NAVAL POSTGRADUATE SCHOOL
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THESIS

THE INFLUENCE OF A LOWER HEATED TUBE ON
NUCLEATE POOL BOILING
FROM A HORIZONTAL TUBE

by

Lannie R. Lake

June 1992

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The Influence of a Lower Heated Tube on Nucleate Pool Boiling from a Horizontal Tube

by

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ABSTRACT

Nucleate pool boiling is an essential part of the vast cooling systems today's combatant ship combat systems are dependent upon. Understanding the mechanisms that influence heat transfer in tube bundles in a liquid pool is the stepping stone for improving these cooling systems. This thesis attempts to bridge the gap between single tube performance and bundle performance by studying the effect of a lower heated tube on the heat transfer from an upper tube in a simple' two tube bundle. This study concludes that a nucleating lower tube (regardless of the spacings tested between tubes) has a significant positive (i.e. improvement of heat transfer) influence an upon upper tube. This is especially evident for a smooth tube where any hysteresis effects are completely eliminated when the lower tube nucleates at a heat flux of 10 kW/m^2 or greater. Furthermore, the only influence for the pitch-to-diameter ratios tested was at the highest heat fluxes for the smooth tubes where a p/d of 1.8 was found to give the maximum heat transfer. No such maximum was obtained for the enhanced tubes.

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NOMENCLATURE

Note that properties and measured parameters of the lower (auxiliary) tube are differentiated from the upper tube with A added to that property or parameter (i.e. ACp is the specific heat of the lower (auxiliary) tube). Though this may cause confusion with area dimensions, this nomenclature is preserved because it is used within programs SETUP72 (appendix C) and DRP72 (appendix D). Note also that like tubes were used in upper and lower positions such that spatial dimensions are the same and are not differentiated between tubes.

A	area
Ab	tube outside surface area of active boiling section
Ac	cross sectional area of the tube
Cp	specific heat
ACp	specific heat of lower (auxiliary) tube
D	diameter
Di	tube inside diameter
Do	tube outside diameter
D1	diameter of the position of the thermocouple
D2	outer diameter of the boiling tube
g	gravitational acceleration
h	heat transfer coefficient
Ah	heat transfer coefficient of lower tube
I	current
AI	current for lower tube
Is	output voltage of AC current sensor
AIs	output voltage of AC current sensor for lower tube
k	thermal conductivity of liquid
Ak	thermal conductivity of liquid associated with lower tube
kc	thermal conductivity of copper
L	active boiling tube length
Lu	non-boiling tube length

Nu	Nusselt number
p	tube outside wall perimeter
Pr	Prandtl number
APr	Prandtl number associated with lower tube
Q	heat transfer rate from boiling surface
AQ	heat transfer rate from boiling surface of lower tube
Qf	heat transfer rate through one non-boiling end
AQf	heat transfer rate through one non-boiling end of lower tube
Qh	heat transfer rate from cartridge heater
AQh	heat transfer rate from lower tube cartridge heater
q″	heat flux
Aq″	heat flux from lower tube
Ra	Rayleigh number
T	temperature
Tavg	average wall temperature at the thermocouple location
ATavg	average wall temperature at the thermocouple location for the lower tube
Tc	critical temperature
Tf	film temperature
ATf	film temperature of fluid associated with lower tube
Tn	temperature of the thermocouple location
Tsat	saturation temperature
Two	outer wall temperature of the boiling test tube
ATwo	outer wall temperature of the lower tube
V	voltage across the cartridge heater
AV	voltage across the cartridge heater for the lower tube
Vs	voltage output by AC-DC true RMS converter
AVs	voltage output by AC-DC true RMS converter for lower tube
α	thermal diffusivity
Aα	thermal diffusivity associated with lower tube
β	volumetric thermal expansion coefficient
Aβ	volumetric thermal expansion coefficient associated with lower tube

δ	uncertainty in measurement and calibration
θ	superheat
$A\theta$	superheat associated with lower tube
μ	dynamic viscosity
$A\mu$	dynamic viscosity associated with lower tube
ν	kinematic viscosity
$A\nu$	kinematic viscosity associated with lower tube
ρ	density
$A\rho$	density associated with lower tube

I. INTRODUCTION

As the United States continues to struggle with the dilemma of increasing requirements for CFC's, while at the same time joining the world in concern over ozone depletion, the exigency of finding replacements for the Navy's high ozone depletion potential fluids is of the highest order. The urgency of this search was made more pressing by the reduction of the time allowed (ordered by President Bush) to meet Montreal Protocol deadlines to purge use of CFC refrigerants. A particularly damaging fluid is R-114, used primarily in centrifugal chilled-water air-conditioning plants onboard ships. In order to best determine a short term or "drop in" replacement, data of R-114 nucleate pool boiling characteristics is required for comparison. The literature provides many studies of single tubes in nucleate pool boiling; however, studies of multiple tubes are more scarce. Most studies of multiple tubes with varied tube spacings were conducted in a manner to simulate a bundle, i.e. all tubes in the pool were studied with the same applied heat flux. There is little work in the literature on the effect of a lower heated tube on the heat transfer from an upper tube (i.e. a simple bundle) and none with R-114. This type of data would begin to bridge the gap between single tube nucleate pool boiling and bundle effects, and would complement the search for a suitable replacement for R-114.

To increase the available data for comparison with possible replacement refrigerants, and to further investigate the effect of tube spacing, the following objectives of this thesis were established:

1. Modify the existing single tube pool boiling apparatus to accommodate a simple two tube bundle, including program modifications to facilitate instrumenting the second tube.
2. Operate the apparatus to prove repeatability with single tube data.
3. Obtain convection and boiling data over several tube pitches and heat flux settings for both a smooth tube and an enhanced tube.

Of particular note is that this study was designed as a follow up to the single tube work of Sugiyama [Ref. 1]. The format of this study, including the correlations and programs used, are adaptations from Sugiyama's work in order to make the results directly comparable.

II. MECHANISMS

A. SINGLE TUBE BEHAVIOR

Experimental heat transfer behavior has been fairly well predicted from single smooth cylindrical tubes in an infinite pool for the natural convection region by Churchill and Chu [Ref. 2] and Churhchill and Usagi [Ref. 3] and, to a lessor degree, for the boiling region by Rohsenow [Ref. 4] and Stephan and Abdelsalam [Ref. 5]. Single enhanced tubes have also been widely studied with nucleate pool boiling enhancements ranging up to 15 times the performance of smooth tubes. The largest enhancements have been obtained for re-entrant cavity surfaces as reported by Yilmaz and Westwater [Ref. 6], Marto and Lepere [Ref. 7], and Wanniarachchi *et al.*[Refs. 8, 9]. In these studies, enhancements were largely attributable to increased surface area in the convection regime, and to stable vapor sites (i.e. vapor trapped in re-entrant cavities), which provided a high density of active nucleation sites at relatively low values of wall superheat in the boiling regime. However, to date, no comprehensive model or correlation has been presented which can predict such enhancements (Thome addresses this in discussion of nucleate pool boiling correlations [Ref. 10]).

B. MULTIPLE TUBE BEHAVIOR

The behavior of a particular tube in a multiple tube environment will be greatly influenced by its neighboring tubes. In both the natural convection and nucleate boiling regimes, fluid heated by a lower tube will rise due to buoyant forces, and an upper tube will tend to be affected, specifically by the heated liquid plume in the convection regime and by the bubble plume in the boiling regime. Also in a bundle the lower tubes may impart a 'drag' on the fluid as it traverses the bundle affecting the fluid reaching an upper tube. The lower tube, because it is not impacted by a similar plume, can be assumed to behave as a single tube in a pool. However, if a bundle is in a confined pool, it may be the case that strong recirculation patterns cause an upper tube, in turn, to affect the heat transfer behavior from a lower tube.

The effect of a lower tube on an upper tube has been studied by Sparrow and Niethammer [Ref. 11] and Marsters [Ref. 12] in the convection region (using air), and by Fujita *et al.* [Ref. 13] and by Hahne, Qiu-Rong and Windisch [Ref. 14] in the nucleate boiling region (using refrigerants). These effects are primarily the result of two contradictory influences, increased fluid velocity in the convection or boiling bubble

plume and increased fluid temperature. In the natural convection region, fluid heated by the lower tube will have a velocity due to buoyant forces when it arrives at the upper tube. In effect the upper tube is no longer in a true natural convection regime but is beginning to experience some forced convection (i.e. mixed convection), thus increasing its heat transfer coefficient. At the same time the heat from the lower tube that causes this buoyant plume to rise has increased the temperature of that fluid within the plume, thereby decreasing the temperature difference between the upper tube and the fluid and decreasing the heat transfer capability. Two of the parameters affecting the strength of these influences are tube separation and the heat flux setting of the lower tube. The temperature of the fluid within the buoyant plume arriving at the top tube will be slightly lower than its temperature when it left the lower tube due to convection to the surrounding fluid. This drop in temperature will tend to increase with increasing tube separation, thereby increasing the ΔT between the upper tube and plume. This implies that the upper tube's heat transfer capability at large pitch may be expected to improve over that at small pitch. In addition, with Sugiyama's [Ref. 1] single tube work, convection plumes were turbulent (Grashof numbers were greater than 10^9), implying that plume velocity will not change with tube separation. However in reality at high enough Grashof numbers, the formation of eddies and other currents in the pool would tend to cause a decrease in the plume fluid velocity at the upper tube and thereby a decrease in the heat transfer coefficient over that of a smaller pitch. These two effects, increasing ΔT with increasing pitch and decreasing heat transfer coefficient at large pitch suggest that an optimum pitch is possible. These influences are confirmed by Sparrow and Niethammer's work with air [Ref. 11] and by Marsters [Ref. 12] with air, for which they found a dependence on the x-based Grashof number (based on the position of the tubes) for the heat transfer from the upper tube.

In the nucleate boiling regime, the above two effects are also important. The fluid entrained in the bubble plume from the lower tube (and the bubbles themselves) impinge upon the upper tube at a much higher velocity than with a convection plume (due to greater buoyant forces associated with the bubbles). This greater velocity of the plume and the bubbles would have the same influence as in convection above and may be sufficient to strip the thermal boundary layer from the upper tube, thereby lowering heat transfer resistance and increasing the heat transfer coefficient. Enhancements due to the impingement of plume and bubbles is most significant at lower heat fluxes when active nucleation site density on the upper tube is low. This provides more 'contact' area between the upper tube and the rising fluid/bubble mixture. As flux is increased on the

upper tube, the active nucleation site density also increases. At high heat fluxes, boiling is so vigorous that the rising fluid is prevented from gaining any appreciable 'contact' with the upper tube. Heat transfer coefficients may then be expected to increase with increasing tube spacing (as in the convection regime) with a possible optimum. However, enhancement due to the lower tube may be expected to decrease when high heat fluxes are applied to the upper tube. The trends of these influences were verified by Fujita *et al.* [Ref. 13] and Hahne *et al.* [Ref. 14].

An additional influence in the boiling regime may be the effect of 'seeding' from the lower tube when it is boiling. At low and medium heat fluxes on the upper tube (active nucleation site density is low), vapor bubbles from the lower tube may impinge and influence enter an inactive cavity on the bottom half of the upper tube. This may prompt an otherwise inactive site to become active earlier than it would have done for a single tube. This influence would also be more effective at low fluxes (low site density) on the upper tube. At higher fluxes, the number of active sites is higher and the probability of an added site becoming active due to this seeding process is significantly lower.

III. DESCRIPTION OF EXPERIMENTAL APPARATUS

A. GENERAL DESCRIPTION

The apparatus used is an adaptation of the apparatus used by Karasabun [Ref. 14: pp 24-41], Reilly [Ref. 15 : pp. 30-44], and Sugiyama [Ref. 1: pp. 8-32] in previous studies of pool boiling of R-114/oil mixtures from single tubes. Karasabun provides complete details of the original configuration of the apparatus. The current apparatus was essentially that used by Sugiyama for single tubes with modifications made to accommodate two tubes in the evaporator. Additionally, the original R-12 cooling system was operated in conjunction with a R-502 system to increase cooling capacity for the increased heat load of two tube operation. An additional smooth and high flux tube were manufactured in order that both a smooth and an enhanced tube set could be studied in the two tube configuration. The unused auxiliary variac power supply was employed as the power supply for the second tube. A two tube data reduction program DRP72 was developed by adapting Sugiyama's single tube data reduction program DRP7.

The apparatus is labeled on a general schematic in Figure 1 and consists essentially of seven components:

1. An evaporator, a boiling vessel assembled using a Pyrex-glass tee with aluminum/teflon endplates.
2. A condenser, assembled using a similar Pyrex-glass tee with aluminum endplates.
3. A reservoir for R-114 liquid storage.
4. A cooling subsystem composed of an 1/2 ton R-502 and a 1/4 ton R-12 refrigeration plant, a 30 gallon water/ethylene glycol sump, and two positive displacement pumps.
5. A vacuum pump.
6. A data acquisition and instrumentation system.
7. An aluminum framework with plexiglass siding within which components 1-3 were housed.

The apparatus was designed for reflux operation. Vapor generated in the evaporator followed a path through an aluminum L-shaped pipe to the condenser. R-114 condensate then returned to the evaporator via copper tubing by gravity. The water/ethylene glycol sump of the cooling subsystem was maintained between -10 and -17 °C. This was accomplished using two separate cooling schemes. The R-502 refrigeration plant cooled the mixture via a counter current heat exchanger through which the

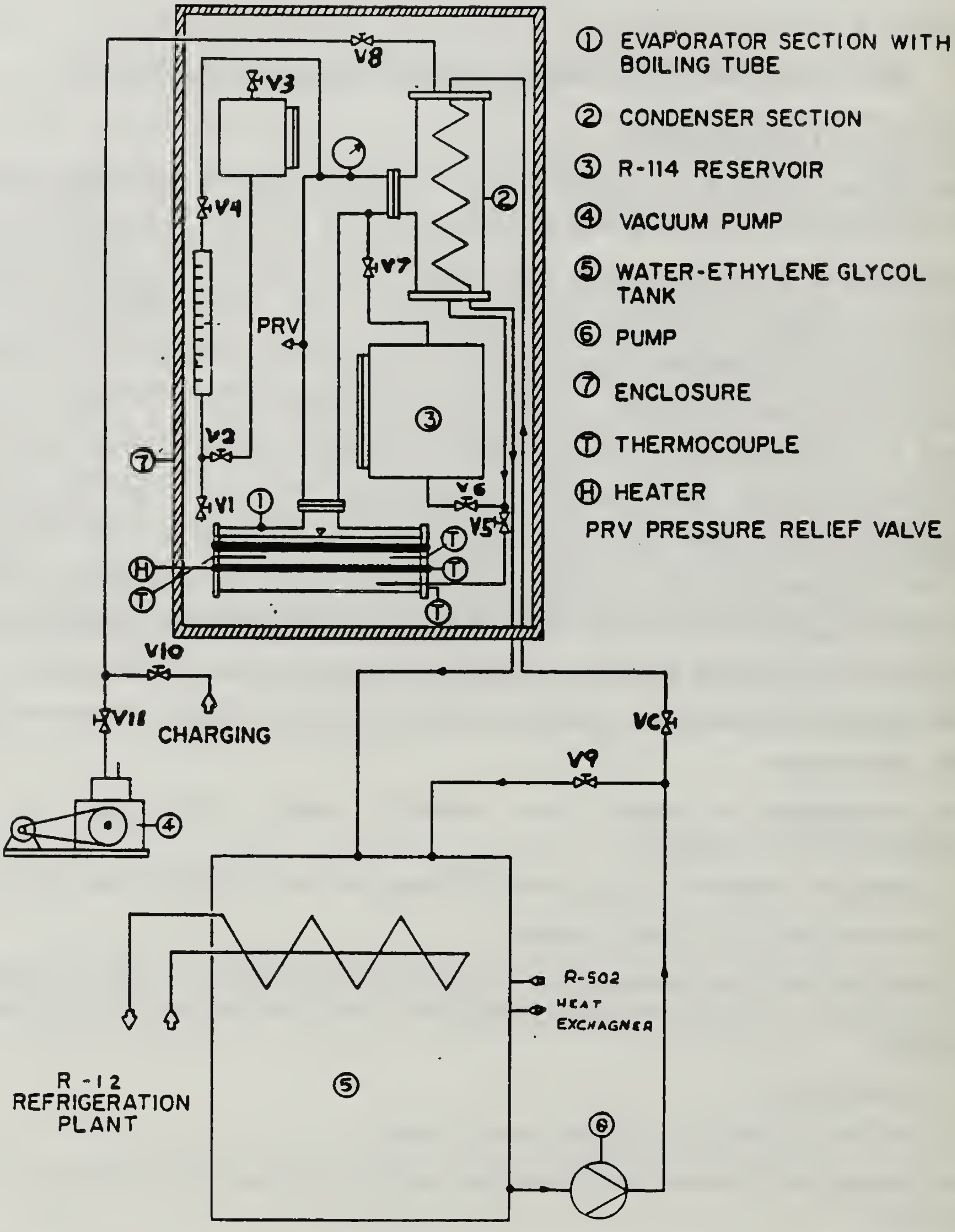


Figure 1. Schematic of Apparatus

water/ethylene glycol mixture was circulated by an 8-gpm turbine-type pump. The R-12 refrigeration plant cooled via an evaporator, constructed of coiled copper tubing, located directly within the sump. The second 8-gpm turbine-type pump circulated the mixture from the sump through copper condensing coils within the condenser via a control valve (VC, see Figure 1), and then returned to the sump.

An alternate mode of operation was used to evacuate the boiler to facilitate tube change out. R-114 was boiled off from the evaporator and condensed as before, but in this case R-114 condensate was directed to the reservoir (by changing certain valves), instead of returning to the evaporator. Once tube changeout was completed the evaporator was simply refilled from the reservoir by gravity.

This study was devoted to pure R-114. In order to ensure that no oil could intrude into the system, the oil path between the oil reservoir and the evaporator (used for R-114/oil mixture tests) was removed and the access to the evaporator plugged. The major components of the oil subsystem (reservoir and graduated cylinder) were left intact for use in future studies.

B. BOILING TEST SECTION

1. Evaporator

The evaporator consisted of a Corning Pyrex-glass tee (3 in. nominal interior diameter) with aluminum endplates. The endplates were coupled to the glass tee by Corning cast iron removable flanges. The glass vessel was mounted horizontally with the side-arm of the tee vertical. The major modification in adapting the apparatus from a single tube to two tubes was to the evaporator endplates. New endplates were manufactured with thermocouple and liquid fill/return penetrations moved to the periphery and a three inch hole centered on the axis of the evaporator. Teflon inserts were manufactured to fit tightly into this hole with varied spacings for the two test tubes. Though the teflon endplates could be rotated to accommodate a variety of tube geometries, only vertical spacing was addressed in this study (i.e. one tube vertically below the other). The addition of another tube to the evaporator also required the liquid level to be raised. The new liquid level was only 10 mm from the top of the Pyrex glass tee and 10 mm above the top of the upper tube (note that for all spacings the upper tube was fixed in position relative to the evaporator and the lower tube was varied). This severely reduced the vapor path between the liquid surface and the top of the evaporator to the exit tee. A comparison of the modified and previous apparatus liquid levels, tube positions and fittings is shown in Figure 2.

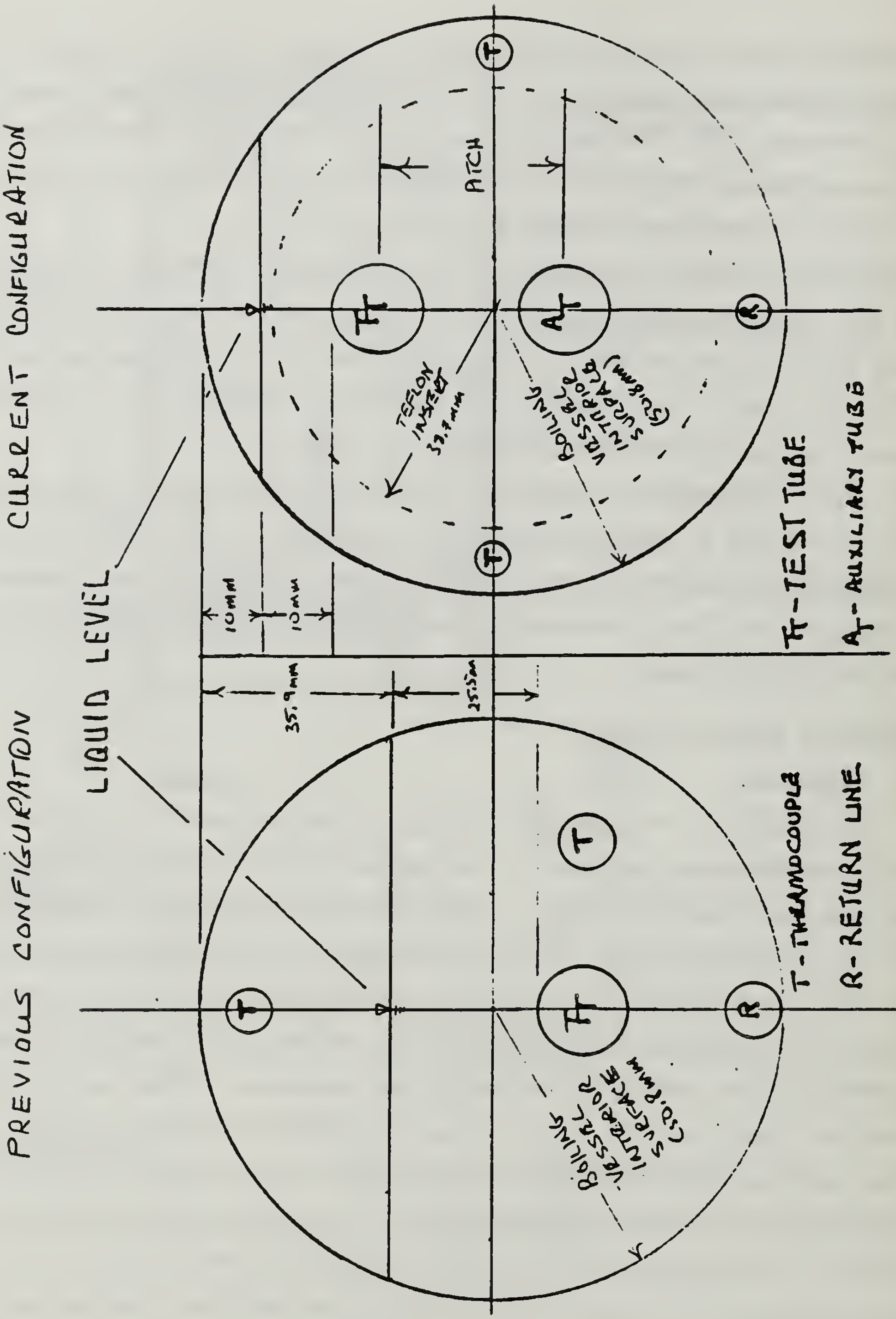


Figure 2. Comparison of Modified and Previous Apparatus

Pyrex-glass was used for both the evaporator and condenser due to its greater strength compared to ordinary glass. It was necessary for the apparatus to withstand pressure differences (between apparatus interior and atmospheric)of up to 20 psig due to possible R-114 vapor pressures at high room temperatures during summer months. In addition, a glass vessel provided several other advantages over a metal one:

- The transparent vessel allowed easy visual observation and videotaping of the boiling phenomena occurring inside.
- The smooth interior surface minimized any nucleate boiling at this inner surface.

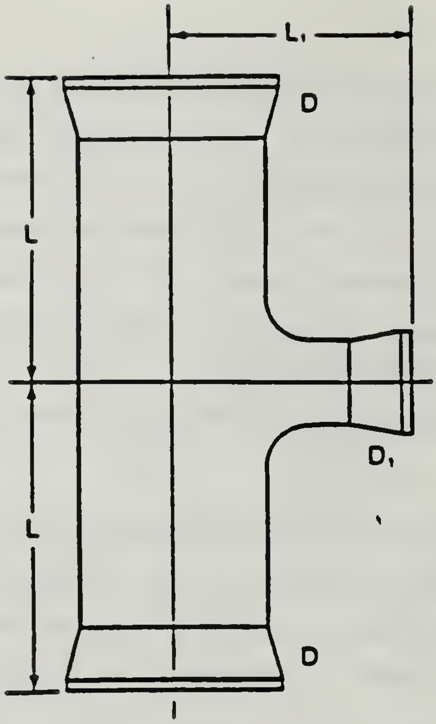
A relief valve (set at 20 psig) was mounted in the aluminum piping between the evaporator and condenser to prevent the safe working pressure (30 psig) of the Pyrex glass tee from being exceeded. A sketch of the glass tee and the cast iron flanges is shown in Figure 3. A sketch of an endplate and a teflon block insert is shown in Figure 4.

2. Test Tubes

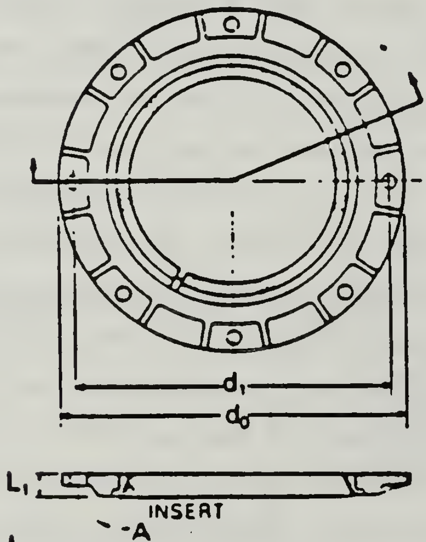
A general schematic of the tubes is shown in Figure 5. The tubes protruded through (and were supported by) the teflon inserts in the endplates of the evaporator. The teflon inserts were sealed by viton O-rings, two O-rings between the teflon inserts and each tube, and one O-ring between the insert and the aluminum endplate.

Two types of tube were used, a smooth hard-copper tube and a High Flux porous-coated tube. The tubes were heated via a stainless steel, 240-volt, 1000-watt (nominal), Watlow Firerod cartridge heater, 6.35 mm in outer diameter, 203.2 mm in actual length with an actual heated length of 190 mm. The heater was tightly inserted into a copper sleeve, which functioned as a mounting device for the thermocouples. The sleeve was then inserted in the tube. Both the heater and the sleeve were tinned with soft solder prior to being inserted into the tube and the whole assembly heated in a furnace to bond the assembly together. This minimized thermal resistance and provided a uniform heat flux along the length of the tube. The heater and sleeve were inserted such that the central 190 mm were heated radially by the heater. This was taken as the active boiling length. A correction was applied for the heat lost from the two ends of the tube in the pool.

The tubes were each instrumented with eight thermocouples soldered into channels which were machined in the outer surface of the sleeve. These thermocouples were located at various axial and circumferential locations as shown in Figure 6. The



a) Corning Pyrex Glass Evaporator ($D \times D_1$ = 402x51 mm, L = 178 mm, L_1 = 127 mm)



b) Cast Iron Flange and Gasket (d_1 = 190mm, d_0 = 210mm, L_1 = 14mm, $A = 21°$)

Figure 3. Sketch of Pyrex Glass Vessels and Flanges

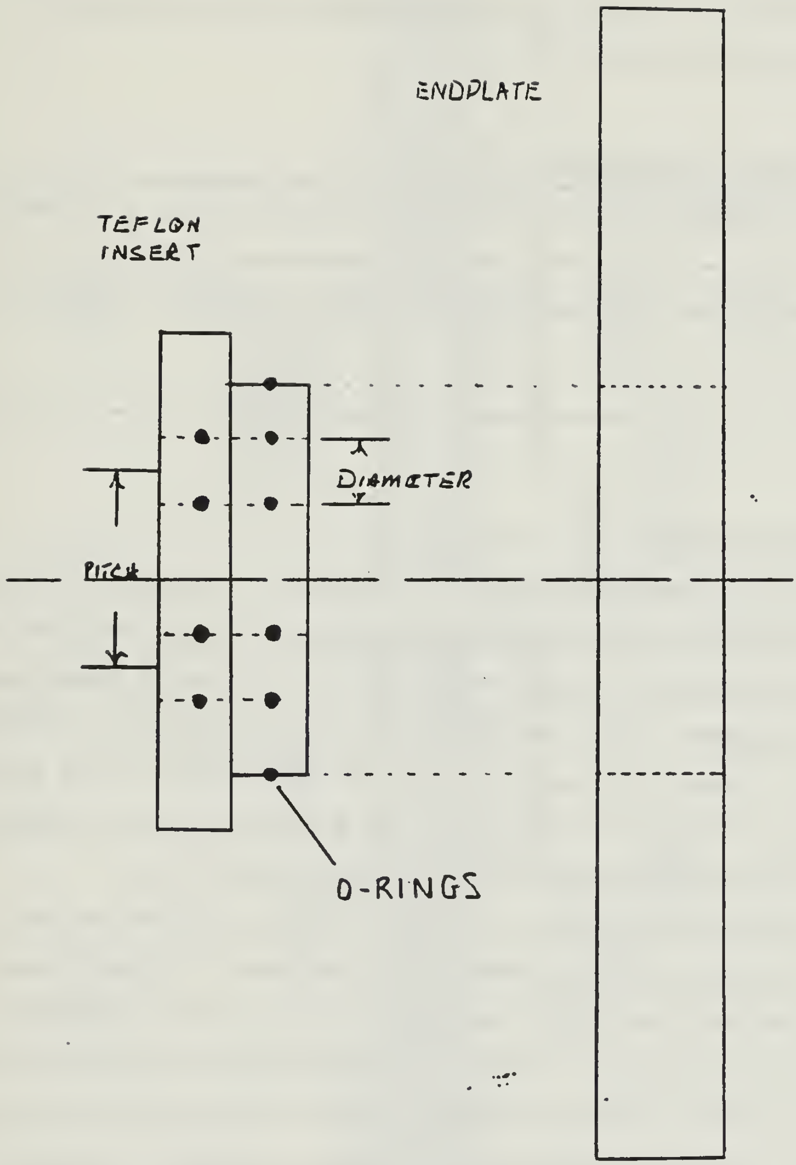


Figure 4. Sketch of Endplates and Teflon Inserts

thermocouple grooves were axially machined to the nearest end of the sleeve to provide a path for the thermocouple leads. Type-T Teflon coated copper-constantan thermocouple wire was used both in the tubes and throughout the apparatus. Dimensions and for the tubes are given in Table 1.

Table 1. TEST TUBE DIMENSIONS

Tube Type	D1(mm)	D2(mm)	Di(mm)	Do(mm)	L(mm)	Lu(mm)	Kwall $(W/m \cdot K)$
Smooth	12.44	15.88	12.70	15.88	190.0	76.20	344
High Flux (95/5 Copper-Nickel)	12.95	15.82	13.20	15.82	190.0	76.20	45

C. CONDENSER SECTION

The condenser was assembled similarly to the evaporator. The same size Pyrex-glass tee was used as the main vessel with aluminum endplates. The glass vessel was mounted vertically with side-arm tee horizontal to receive the R-114 vapor. A helical condensing coil made of 9.5 mm copper tubing was inserted in the Pyrex glass tee. Swagelock fittings were used to connect the condenser coil to the coolant tubing through the condenser endplates. The coil was fabricated to an approximate outside diameter of 76 mm, providing an active condensation length of approximately 4.5 m.

The vacuum pump was connected to the top of the condenser via two isolation valves to remove any noncondensable gases that collect there. A tubing connection was placed in the bottom endplate of the condenser to enable R-114 condensate to drain back to the evaporator by gravity. Valve and tubing lineup was such that condensate could also be directed back to the R-114 reservoir. The condenser was connected to the evaporator by an L shaped aluminum tube two inches in diameter. The pressure relief valve, mentioned earlier, and a bourdon pressure gage were mounted on this aluminum tube.

D. COOLING SECTION

1. Coolant Sump

A 0.15 m^3, rectangular sump for the water-ethylene glycol mixture was made of 13 mm Plexiglas sheet. The sides were glue jointed using a methylene chloride solution with additional support provided by small screws. The tank was placed on a wooden

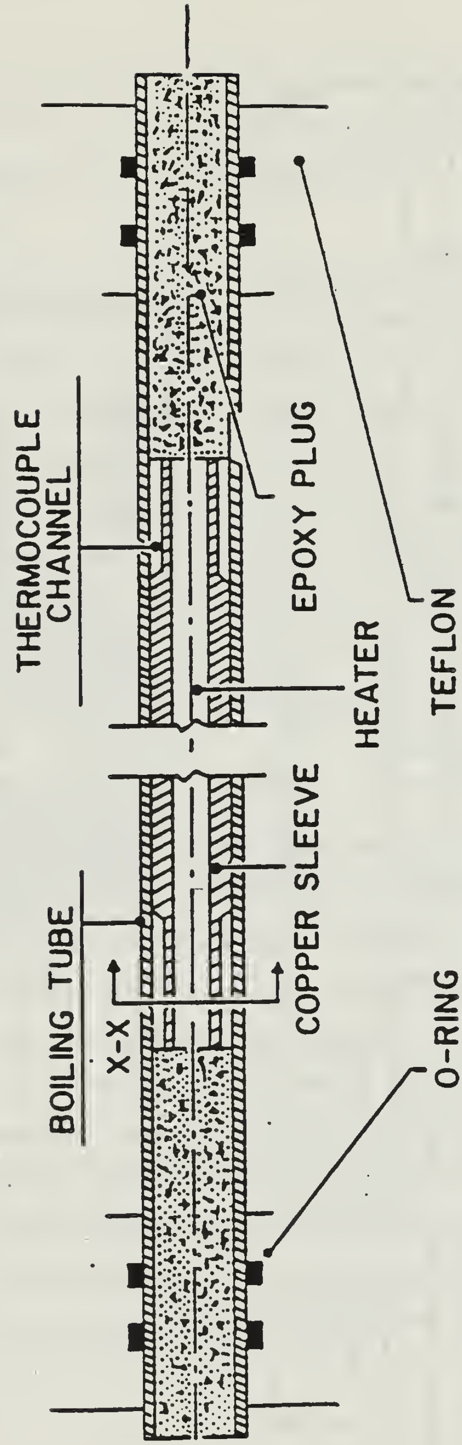


Figure 5. Schematic of the Test Tube

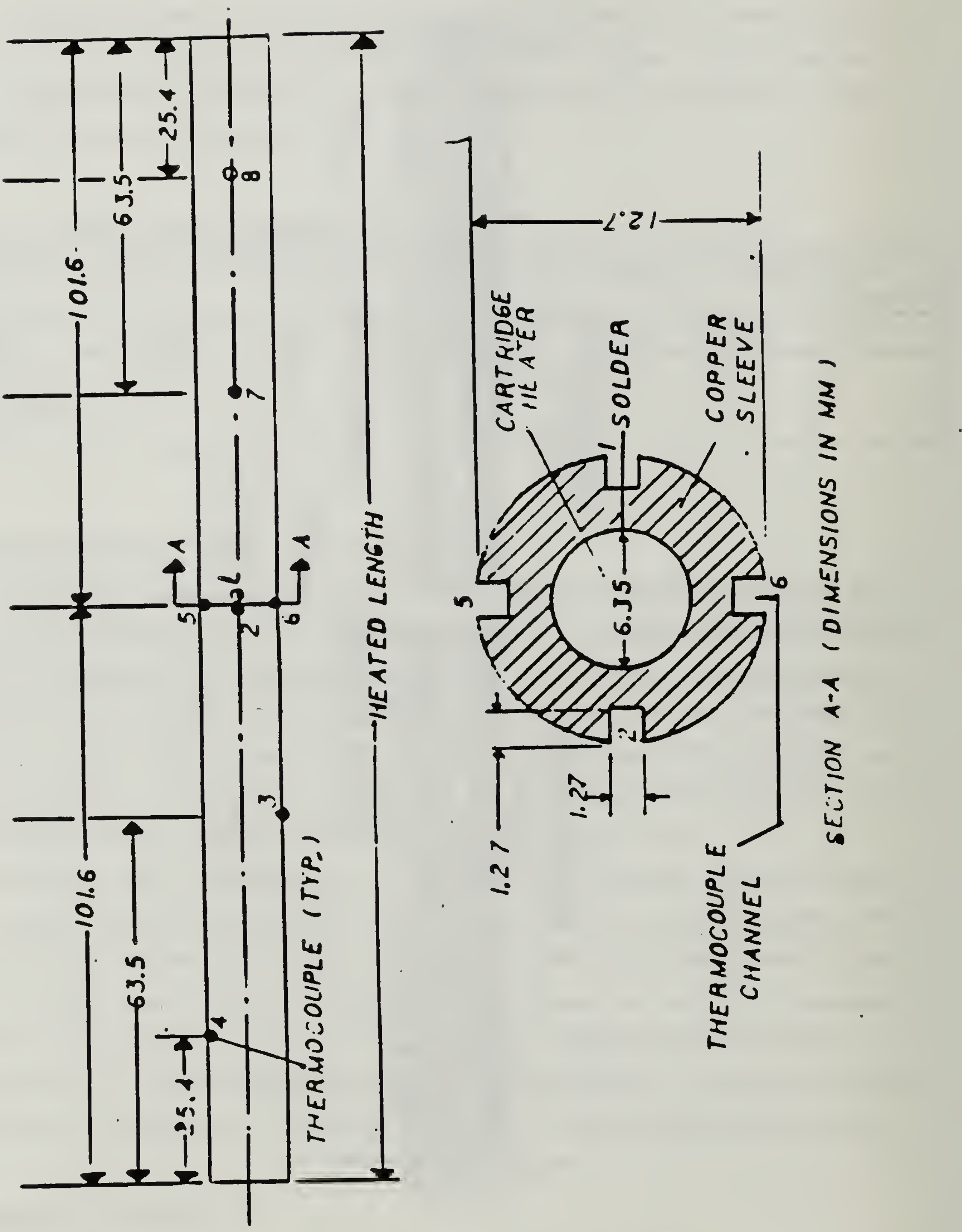


Figure 6. Positions of the Thermocouples

platform to separate it from the concrete floor and all sides were insulated with 22 mm sheet insulation. The coolant was a 52% mixture of ethylene glycol/distilled water producing a solution freezing point of approximately -25 °C.

2. Refrigeration Plants

A 1/2 ton R-502 and a 1/4 ton R-12 refrigeration plant were used to chill the ethylene glycol/water mixture. Each consisted of a hermetically sealed compressor assembly, an air cooled condenser, a receiver, a filter-dryer, a pressure regulator, a temperature control switch and a thermostatic expansion valve. A counter current heat exchanger was used as the evaporator for the R-502 plant. An evaporator for the R-12 plant was constructed of 9.5 mm copper tubing which was coiled and placed directly in the coolant sump. Both plants were controlled by a temperature control switch with each plant having its own thermostatic expansion valve. The plants were adjusted to maintain coolant temperatures at about -17 °C. Figure 7 shows a schematic of the R-502 refrigeration plant. Figure 1 shows placement of the R-12 refrigeration plant evaporator.

3. Pump and Control Valve

The two 8 gpm, 115 V Burks turbine type, positive-displacement pumps were floor mounted next to the coolant sump. One pumped the ethylene glycol/water coolant mixture through the R-502 counter-current heat exchanger. The other pumped the coolant mixture to the condensing coil via control valve VC (see Figure 1). Valve VC was the operators primary control device to maintain saturation pressure at a desired value by varying the coolant flow rate (and hence the condensation rate) in the condenser. A bypass line was also installed on the discharge line from the pump. Discharge bypass was controlled by valve V9. The bypass line served to avoid overloading the positive displacement pump when small heat loads were placed on the condenser (low coolant flow rates). The bypass return line returned to the sump via a penetration in the top of the tank, where the coolant return stream from the condenser returned as well.

E. R-114 RESERVOIR

The R-114 reservoir was an aluminum cylindrical vessel, 230 mm in diameter and 254 mm in height. The reservoir was equipped with a transparent plastic tubular sight glass to monitor liquid level. The reservoir was located within the apparatus enclosure at a vertical location above that of the evaporator and below that of the condenser to facilitate both gravity flow from the condenser to the reservoir and from the reservoir

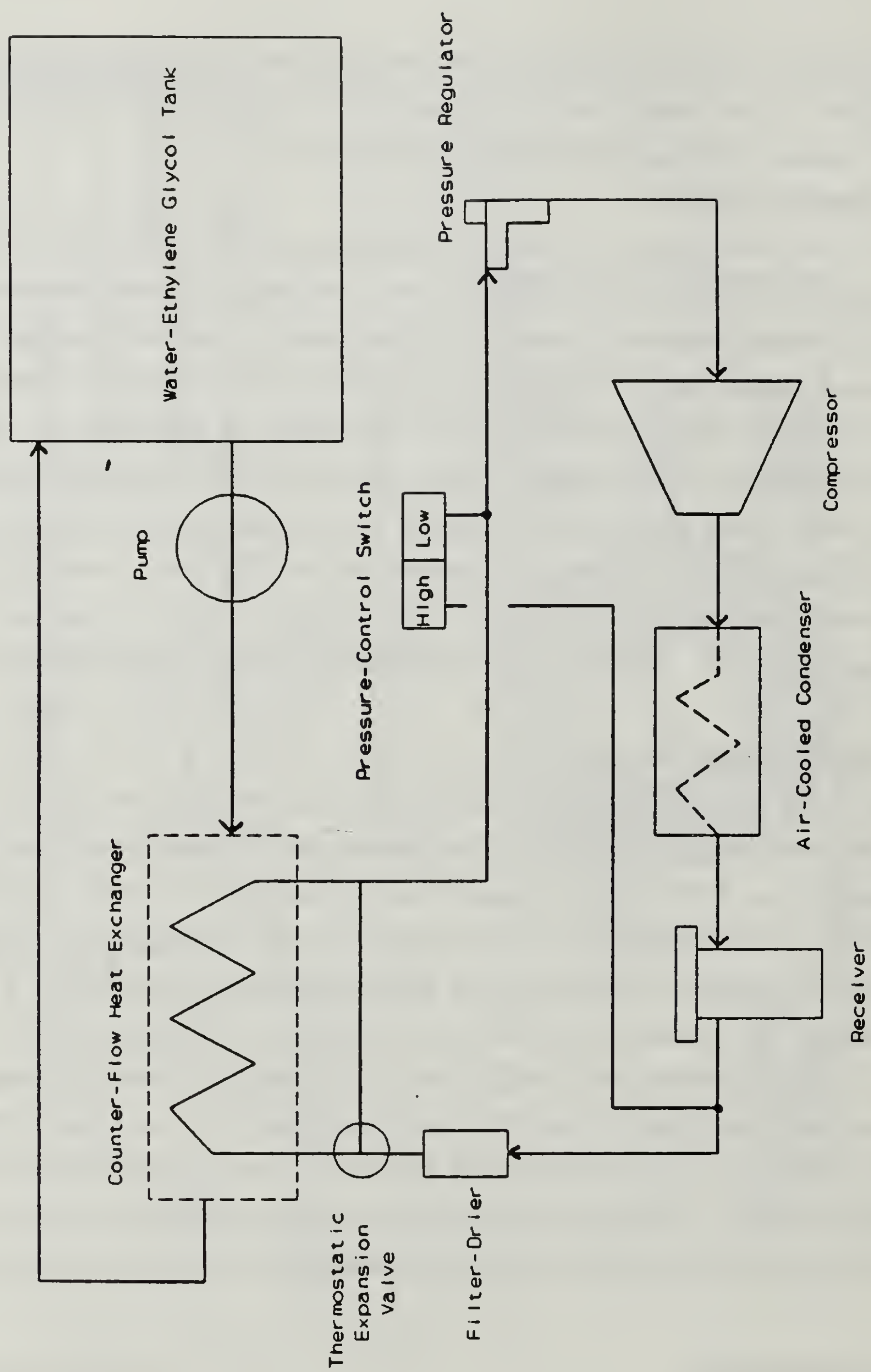


Figure 7. Schematic of R-502 Refrigeration System

to the evaporator. The reservoir could be replenished from an outside source (storage cylinder) via a connection on the vacuum line from the condenser. Vapor from the storage cylinder was condensed in the condenser and drained into the reservoir. The arrangement of the reservoir is shown in Figure 1.

F. APPARATUS ENCLOSURE

The apparatus (apart from the cooling subsystem) was contained in an aluminum framed, plexiglas enclosure. The enclosure consisted of a rectangular welded frame approximately 1 m x 0.5 m x 0.6 m. The frame was divided into upper and lower halves with the lower half of the frame straddling and enclosing the coolant sump. The upper half of the frame was enclosed at the top and bottom with aluminum sheet. The four remaining sides were enclosed with 13 mm Plexiglas. The opposing 0.5 m x 0.6 m plexiglas sides were equipped with hinges to allow access to the interior. The refrigeration plants, pumps, and heat exchanger were located on the laboratory floor adjacent to the enclosure. Data acquisition equipment was located in a separate cabinet also adjacent to the enclosure. The enclosure provided some insulation from ambient conditions and provided a safety barrier between personnel and the apparatus should one of the glass vessels fail.

G. INSTRUMENTATION

1. Power Measurement

A 240 volt AC supply was used as the power source for the apparatus and was controlled via a variac. Output from the variac ranged from 0-220 V, 0-5 A, adjustable by the operator, to obtain a desired heat flux at the tube surface. Power input to the tube heater was measured with an AC current sensor and a voltage sensor (both sensors output in volts). The voltage sensor output was also processed through an AC-DC true R.M.S. converter which provided a proportional output signal (also in volts). The current and R.M.S. voltage output were input to the data acquisition system. Calibration of power measurement was checked by comparing voltage and amperage measurements against a digital voltmeter and ammeter. The power measurement system is shown schematically in Figure 8.

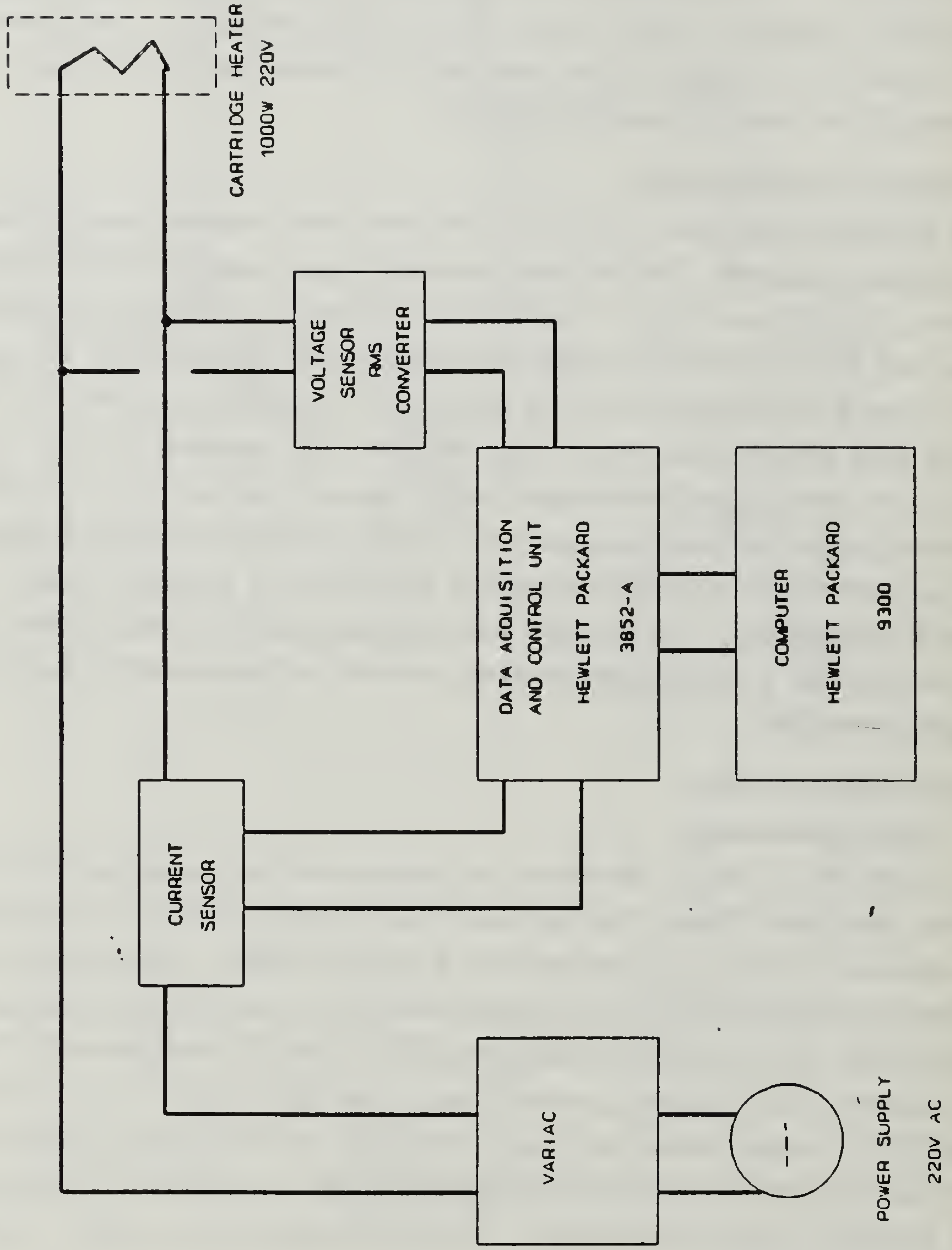


Figure 8. Schematic of the Power Measurement

2. Temperature Measurement

Several temperatures were monitored throughout the apparatus. These were

- Average test tube wall temperature (using the 8 thermocouples positioned as mentioned above).
- Pool temperature (three thermocouples located at three different positions longitudinally within the pool but at approximately the same height)
- Coolant sump temperature (one thermocouple)

The pool thermocouples were inserted into special housings that penetrated the evaporator endplates (Figure 9). The main body of the housing was manufactured from stainless steel (low thermal conductivity) to minimize errors in pool temperature measurement due to conduction from the surroundings through the housing. The tip of the housing was manufactured from copper to take advantage of copper's high thermal conductivity and to minimize the temperature difference between the pool and the thermocouple.

Copper-constantan thermocouples were used for all measurements. Thermocouples were read directly by a Hewlett-Packard 3497A data acquisition system controlled by a Hewlett-Packard 9826 computer. The average temperature for each thermocouple was obtained by scanning its output 20 times over 5 seconds and taking an average.

H. DATA ACQUISITION AND REDUCTION

All sensor outputs (thermocouples, current sensor and R.M.S. voltage) were analyzed by a Hewlett-Packard 9826 computer and the data stored using the iterative data collection/reduction program DRP72 (Sugiyama's single tube program DRP71 [Ref. 1] was used during initially repeatability experiments). The program was controlled (by the operator) by keyboard interaction to prompt the system to take desired steps. Raw data was stored on the computer hard drive while a printout of reduced data was provided on a Hewlett-Packard Inkjet printer. Channel assignments for the various sensor inputs to the data acquisition system are shown in Table 2.

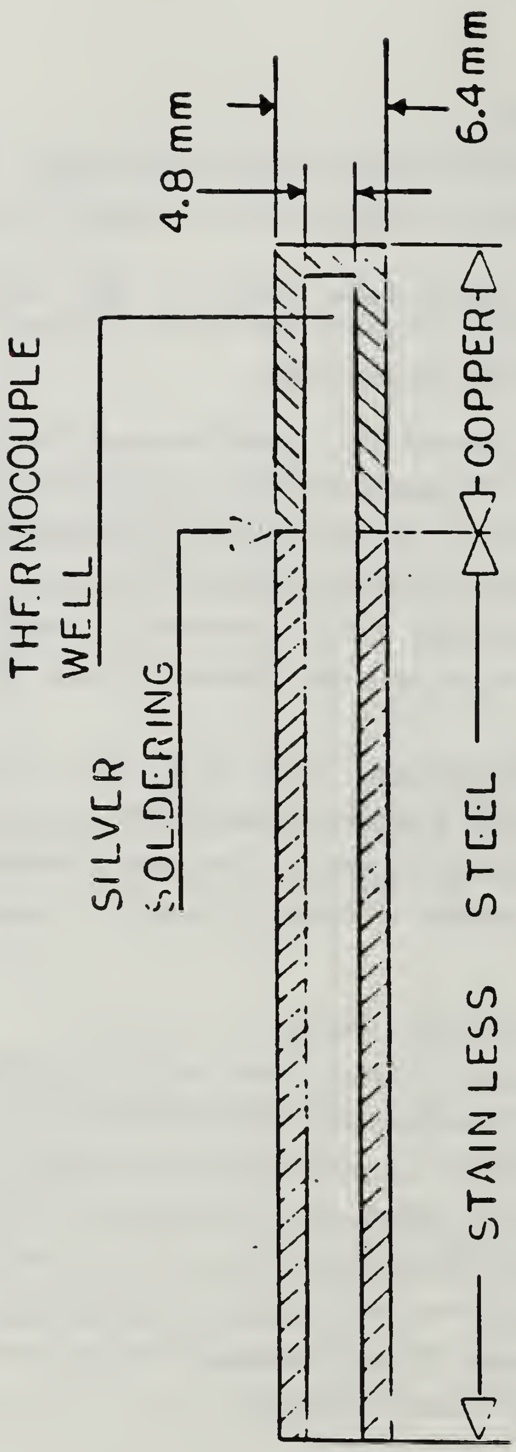


Figure 9. Sketch of Thermocouple Housing

Table 2. HP 3497A CHANNEL ASSIGNMENTS

Channel	Assignment
00-07	Upper test tube wall temperatures
08-15	Lower test tube wall temperatures
16-18	Pool liquid temperatures
19	Coolant sump temperature
20	RMS voltage tube heaters
21	Upper tube current sensor
22	Lower tube current sensor

Following data acquisition, the data were reduced utilizing the following procedure[1]:

1. Input the name of the user-specified file to be stored on hard drive.
2. Select number of tubes to be powered and from which tube data is to be collected (upper or lower).
3. Select tube type (all dimensions of the boiling test tubes are then automatically selected).
4. Set desired saturation temperature (°C) of the pool (for these tests, 2.2 °C was used, corresponding to approximately 1 atmosphere).
5. Input desired heat flux setting.
6. Set desired heat fluxes by adjusting appropriate variac.
7. Set desired saturation temperature by adjusting flow of coolant through condenser coils with control valve VC.
8. Once saturation temperature is achieved, wait for steady state conditions (minimum of 5 minutes) prior to taking data.
9. Prompt data acquisition unit to scan all channels listed in Table 2. All channel readings are made in volts and stored in user specified fields.
10. Compute parameters from these voltages (i.e. temperature and power).
11. Compute the heat transfer rate from the cartridge heater.
12. Compute the average wall temperature of the test tubes and calculate the wall superheat (Twall – Tsat)
13. Compute the physical properties of R-114 using the property correlations (see Sugiyama[Ref. 1]) at film temperature ((Twall –Tsat)/2).
14. Compute the natural convection heat-transfer coefficient of R-114 from the unheated ends of the test tubes.
15. Compute heat losses from the unheated ends of each tube.
16. Calculate heat flux from the heated length of each tube.
17. Calculate the heat-transfer coefficient of the R-114 from the heated length of each tube.
18. Store heat flux and wall superheat for each data set in user specified field.
19. Plot the data using available software. For this study, plots were produced on the NPS mainframe computer.

Sample calculations of the above procedure are given in Appendix A.

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[1] This procedure was essentially identical to that followed by Sugiyama [Ref. 1] and therefore his procedure is largely reproduced.

IV. EXPERIMENTAL PROCEDURE

A. ASSEMBLY

The mechanical assembly of the tubes within the evaporator was very straight forward and will not be discussed in great detail. However the preparatory steps following assembly are important from the point of view of ensuring a leaktight apparatus to prevent loss of R-114 from the system and the intrusion of noncondensable gases into the system. Additionally it should be noted that vertical alignment of tubes was ensured by using an air bubble level.

1. Pressure Test of the Apparatus

Following reassembly of the evaporator, a pressure test was conducted on the apparatus by pressurizing the system (with air) up to 10 psig. A soap-water mixture then was sprayed on all joints and leaks were detected by bubble formation from the soap-water mixture. Any leaks were then repaired. The apparatus was repeatedly pressure tested until there were no "visible" leaks detected.

2. Vacuum Test

Following a successful pressure test, the apparatus was evacuated (using the vacuum pump) to approximately 27 inHg. The apparatus was then allowed to stand overnight. If an appreciable vacuum loss was observed (i.e. a drop of more than 1 inHg. in a 24 hour period), the whole process was repeated, beginning with a pressure test, until all leaks were corrected.

3. Filling the Evaporator

After the apparatus was successfully vacuum tested, the evaporator was filled from the R-114 reservoir. The pressures were first equalized between the evaporator and the reservoir by cracking open valve V7. R-114 liquid was then drained by gravity into the evaporator through valve V6 until the liquid reached the desired evaporator level, approximately 10 mm above the top of the upper tube. Once the evaporator was filled, the reservoir was isolated from the rest of the apparatus by closing all connecting valves.

4. Sensor Connections

Thermocouple leads and any other sensor connections were not reconnected until the evaporator was successfully filled without leaks. This prevented unnecessary wear and tear on the heater leads and thermocouple wire due to the large number of tube changes required.

5. Degassing and Acquisition Channel Check

Once all connections were made, program SETUP72 checked the output on all channels. Any erroneous output was promptly investigated and the necessary corrections made. Before any heat was applied to either test tube, the system pressure was reduced to the desired saturation pressure by opening flow of the coolant mixture to the condenser. Each tube in turn was boiled vigorously at the highest heat flux setting (approximately 80 kW/m^2) for about 10 minutes in order to degas the refrigerant and to remove excess air from the tube surface cavities. Noncondensable gases then collected at the top of the condenser and were removed by the vacuum pump. During the degassing procedure, program SETUP72 was again used to observe thermocouple readings and power sensors to ensure proper operation. Any faulty thermocouples were marked to ensure they were excluded during data runs. Following degassing, the apparatus was secured and the tubes allowed to soak overnight in the R-114 pool to provide good surface wetting.

B. NORMAL PROCEDURE

The following procedure was used to obtain heat transfer data[2]:

1. Prior to system startup, the refrigeration plants were operated for approximately 1 hour to reduce the coolant sump temperature to about -15 °C.
2. The data acquisition/control unit, computer and variac panel were switched on.
3. The computer program SETUP72 was loaded and run: 1) All data acquisition channels were then rechecked. 2) A power output of approximately 2.5 Watts was input into each tube to check operation of the heater and power sensors. 3) The average temperature of the refrigerant was slowly reduced to 2.2 °C by circulating a small amount of coolant through the condenser.
4. The data acquisition program DRP72 was loaded and run.
5. The desired heat flux setting for the lower tube was input to the program and the lower tube variac adjusted to give the desired heat flux (within $\pm$ 500 W/m^2).
6. The control valve VC was adjusted to regulate the flow of cooling liquid through the condenser to maintain a constant saturation temperature at a given heat flux. Desired versus actual saturation temperatures were monitored continuously by the program until they agreed to within $\pm$ 0.1 °C.
7. For each data point, conditions in the evaporator were allowed to stabilize for at least five minutes prior to taking data. The following raw data were measured and stored in a user specified field: local test tube wall temperatures, pool liquid temperatures, sump temperature, current sensor readings and voltage sensor readings.

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2 Ibid

8. Two data points were taken at each desired heat flux and saturation temperature. The following processed data were recorded as a printout: wall temperatures of the test tubes, liquid pool temperatures, vapor temperature, sump temperature, wall superheat, heat-transfer coefficient and the heat flux.

9. For each data set, the above procedure was repeated from step 5. Various heat flux steps were used to obtain uniform steps on a log-log scale. For increasing flux, smaller steps were used up until the incipience of boiling in order to accurately determine the point of incipience.

C. DATA LISTING

Data were filed using the following file name system:

- Files were given 10 character names (ex. DAT0531I52).
- The first three characters DAT simply refer to data.
- The next four characters date the file (0531= 31 May).
- The eighth character indicated an increasing or decreasing run (I = increasing, D = decreasing).
- The ninth character indicated tube type ad listed in program DRP72 (4 = smooth tube, 5 = High Flux tube).
- The tenth character indicated which program wad used DRP71 or DRP72 (1 = DRP71, 2 = DRP72).
- The 11th character when present indicated successive runs for the indicated tube and indicated program for that day.

Table 3 is a listing of data runs.

Table 3. LISTING OF DATA RUNS

Data File	Tube Type	Purpose
DAT0122I51	High Flux	Cal; repeatability; single tube
DAT0123I52	High Flux	Cal; repeatability; single tube
DAT0125I52	High Flux	Repeatability; p/d = 2
DAT0127I2	High Flux	Repeatability; p/d = 2
DAT0130I52	High Flux	Repeatability; p/d = 2
DAT0130D52	High Flux	Repeatability; p/d = 2
DAT0312I42	Smooth	Data; repeatability; p/d = 2
DAT0312D41	Smooth	Data; repeatability; p/d = 2
DAT0313I41	Smooth	Repeatability; p/d = 2
DAT0313D41	Smooth	Repeatability; p/d = 2
DAT0317I42	Smooth	Repeatability; p/d = 2
DAT0317D42	Smooth	Repeatability; p/d = 2
DAT0320I41	Smooth	Repeatability; p/d = 2
DAT0320D41	Smooth	Repeatability; p/d = 2
DAT0330I42	Smooth	Repeatability; p/d = 2
DAT0330D42	Smooth	Repeatability; p/d = 2
DAT0331I42	Smooth	Data; p/d = 2; 500 W/m^2 on lower tube
DAT0331D42	Smooth	Data; p/d = 2; 500 W/m^2 on lower tube
DAT0401I42	Smooth	Data; p/d = 2; 1 kW/m^2 on lower tube
DAT0401D42	Smooth	Data; p/d = 2; 1 kW/m^2 on lower tube
DAT0404I42	Smooth	Data; p/d = 2; 1 kW/m^2 on lower tube
DAT0404I421	Smooth	Data; p/d = 2; 1 kW/m^2 on lower tube
DAT0404D421	Smooth	Data; p/d = 2; 1 kW/m^2 on lower tube
DAT0406I42	Smooth	Data; p/d = 2; 10 kW/m^2 on lower tube

Continuation of Table 3.

Data File	Tube Type	Purpose
DAT0406D42	Smooth	Data; p/d = 2; 10 kW/m^2 on lower tube
DAT0407I42	Smooth	Data; p/d = 2; 25 kW/m^2 on lower tube
DAT0407D42	Smooth	Data; p/d = 2; 25 kW/m^2 on lower tube
DAT0408I42	Smooth	Data; p/d = 2; 3 kW/m^2 on lower tube
DAT0408D42	Smooth	Data; p/d = 2; 3 kW/m^2 on lower tube
DAT0410I42	Smooth	Data; p/d = 2; Tubes run up together
DAT0410D42	Smooth	Data; p/d = 2; Tubes run down together
DAT0415I42	Smooth	Data; p/d = 1.8; 10 kW/m^2 on lower tube
DAT0415D42	Smooth	Data; p/d = 1.8; 10 kW/m^2 on lower tube
DAT0415I421	Smooth	Data; p/d = 1.8; 25 kW/m^2 on lower tube
DAT0415D421	Smooth	Data; p/d = 1.8; 25 kW/m^2 on lower tube
DAT0417I42	Smooth	Data; p/d = 1.8; no power on lower tube
DAT0417D42	Smooth	Data; p/d = 1.8; no power on lower tube
DAT0418I42	Smooth	Data; p/d = 1.8; 1 kW/m^2 on lower tube
DAT0418D42	Smooth	Data; p/d = 1.8; 1 kW/m^2 on lower tube
DAT0419I42	Smooth	Data; p/d = 1.8; 3 kW/m^2 on lower tube
DAT0419D42	Smooth	Data; p/d = 1.8; 3 kW/m^2 on lower tube
DAT0423I42	Smooth	Data; p/d = 1.5; no power on lower tube

Continuation of Table 3

Data File	Tube Type	Purpose
DAT0423D42	Smooth	Data; p/d= 1.5; no power on lower tube
DAT0424I42	Smooth	Data; p/d= 1.5; 3 kW/m^2 on lower tube
DAT0424D42	Smooth	Data; p/d= 1.5; 3 kW/m^2 on lower tube
DAT0425I42	Smooth	Data; p/d= 1.5; 1 kW/m^2 on lower tube
DAT0425D42	Smooth	Data; p/d= 1.5; 1 kW/m^2 on lower tube
DAT0426I42	Smooth	Data; p/d= 1.5; 10 kW/m^2 on lower tube
DAT0426D42	Smooth	Data; p/d= 1.5; 10 kW/m^2 on lower tube
DAT0427I42	Smooth	Data; p/d= 1.5; 25 kW/m^2 on lower tube
DAT0427D42	Smooth	Data; p/d= 1.5; 25 kW/m^2 on lower tube
DAT0430I52	High Flux	Data; p/d= 1.5; 1 kW/m^2 on lower tube
DAT0430D52	High Flux	Data; p/d= 1.5; 1 kW/m^2 on lower tube
DAT0501I52	High Flux	Data; p/d= 1.5; 10 kW/m^2 on lower tube
DAT0501D52	High Flux	Data; p/d= 1.5; 10 kW/m^2 on lower tube
DAT0501I522	High Flux	Data; p/d= 1.5; 25 kW/m^2 on lower tube
DAT0501D522	High Flux	Data; p/d= 1.5; 25 kW/m^2 on lower tube
DAT0502I52	High Flux	Data; p/d= 1.5; 3 kW/m^2 on lower tube
DAT0502D52	High Flux	Data; p/d= 1.5; 3 kW/m^2 on lower tube
DAT0503I52	High Flux	Data; p/d= 1.5; no power on lower tube

Continuation of Table 3.

Data File	Tube Type	Purpose
DAT0503D52	High Flux	Data; p/d = 1.5; no power on lower tube
DAT0506I52	High Flux	Data; p/d = 1.8; no power on lower tube
DAT0506D52	High Flux	Data; p/d = 1.8; no power on lower tube
DAT0507I52	High Flux	Data; p/d = 1.8; 1 kW/m^2 on lower tube
DAT0507D52	High Flux	Data; p/d = 1.8; 1 kW/m^2 on lower tube
DAT0508I52	High Flux	Data; p/d = 1.8; 3 kW/m^2 on lower tube
DAT0508D52	High Flux	Data; p/d = 1.8; 3 kW/m^2 on lower tube
DAT0508I521	High Flux	Data; p/d = 1.8; 10 kW/m^2 on lower tube
DAT0508D521	High Flux	Data; p/d = 1.8; 10 kW/m^2 on lower tube
DAT0509I52	High Flux	Data; p/d = 1.8; 25 kW/m^2 on lower tube
DAT0509D52	High Flux	Data; p/d = 1.8; 25 kW/m^2 on lower tube
DAT0509D52	High Flux	Data; p/d = 1.8; 25 kW/m^2 on lower tube
DAT0515I52	High Flux	Data; p/d = 2; 25 kW/m^2 on lower tube
DAT0515D52	High Flux	Data; p/d = 2; 25 kW/m^2 on lower tube
DAT0516I52	High Flux	Data; p/d = 2; 10 kW/m^2 on lower tube
DAT0516D52	High Flux	Data; p/d = 2; 10 kW/m^2 on lower tube
DAT0517I52	High Flux	Data; p/d = 2; 1 kW/m^2 on lower tube
DAT0519I52	High Flux	Data; p/d = 2; 3 kW/m^2 on lower tube

Continuation of Table 3

Data File	Tube Type	Purpose
DAT0520I52	High Flux	Data; p/d = 2; no power on lower tube
DAT0529I52	High Flux	Data; p/d = 2; tubes run up/down together
DAT0530I52	High Flux	Data; p/d = 2; lower tube position plugged

V. RESULTS AND DISCUSSION

It should be noted and it is stressed that results are expressed in terms of enhancement of the upper tube over a single tube and that the results are applicable to this apparatus. These results may not be reproducible outside of this apparatus.

A. REPRODUCIBILITY

To investigate repeatability, tests were conducted with both a 'single' High Flux and smooth tube (with only the upper tube operating). Runs were conducted using both program DRP71 (from Sugiyama's single tube work [Ref. 1]) and DRP72 with no heat flux applied to the bottom tube. This ensured that the new program DRP72 performed correctly. An additional set of runs were made using the pair of smooth tubes with a heat flux of 1 kW/m^2 applied to the lower tube using program DRP72. The runs for all these comparisons are listed in Table 4. A pitch-to-diameter ratio of 2 was used for the runs listed in Table 4. A plot of heat flux vs. wall superheat (Thetab) for these runs is shown in Figure 10 through Figure 12. Figure 10 shows the 'single' smooth tube data together with the single smooth tube data of Sugiyama [Ref. 1]. The three runs agree very well and are within 10% of Sugiyama's data; any discrepancy is attributed to the presence of the unheated lower tube modifying the flow over the upper tube. Clear evidence of hysteresis is seen as with Sugiyama's work; as the heat flux is decreased , a closed loop is formed indicating that as the nucleation sites die out, the transfer mechanism returns to one of natural convection. Figure 11 shows the 'single' High Flux tube data together with the single tube High Flux data of Sugiyama [Ref. 1]. Again good agreement is obtained except at the lowest heat fluxes and lowest ΔT's where discrepancies of up to 50% are noted. However, due to the very high uncertainty in this region (marked on Figure 11), primarily due to uncertainty in the wall temperature measurement due to the fabrication procedures, the agreement is still considered reasonable. It should also be noted that run DAT0530 was conducted with plugs in place of the bottom tube (as opposed to the bottom tube having zero applied heat flux) and also shows excellent agreement. This indicates quite clearly that with the lower tube off, the upper tube behaves almost exactly like a single tube. Note also that the hysteresis 'loop' is open (again similar to the work of Sugiyama) indicative of the fact that there are still a significant number of active nucleation sites operating with the High Flux tube even at heat fluxes as low as 1000 W/m^2. Figure 12 shows the three smooth tube runs con-

ducted with a $1 kW/m^2$ heat flux applied to the bottom tube. Without discussing the significance of the results here (see section B.), it can be seen that repeatability is good and within 5% for all three data sets. Based on Figure 10 through Figure 12, data repeatability and agreement with past single tube work carried out on the same apparatus is considered good.

Table 4. DATA RUNS USED FOR REPEATABILITY

Data Set	Tube Type	Lower Tube Setting
DAT0313I41	smooth	no power on lower tube
DAT0313D41	smooth	no power on lower tube
DAT0320I41	smooth	no power on lower tube
DAT0320D41	smooth	no power on lower tube
DAT0330I42	smooth	no power on lower tube
DAT0330D42	smooth	no power on lower tube
DAT0401I42	smooth	$1 kW/m^2$
DAT0401D42	smooth	$1 kW/m^2$
DAT0404I42	smooth	$1 kW/m^2$
DAT0404D42	smooth	$1 kW/m^2$
DAT0407I42	smooth	$1 kW/m^2$
DAT0407D42	smooth	$1 kW/m^2$
DAT0123I52	High Flux	no power on lower tube, increasing run only
DAT0130I52	High Flux	no power on lower tube
DAT0130D52	High Flux	no power on lower tube
DAT0530I52	High Flux	lower tube removed and position plugged, increasing and decreasing run recorded in this file

B. INFLUENCE OF THE LOWER TUBE

To investigate the influence of a lower upon an upper tube, each upper tube (for both types of tube surface) was run up and down (starting in the convection region) through various heat flux settings for three different pitch-to-diameter (p/d) ratios and five different fixed heat flux settings on the lower tube. Note that in each test, the same tube surface was used for the upper tube and the lower tube (i.e. the surfaces were never mixed). The p/d ratios used were 1.5, 1.8 and 2. A p/d ratio of 2 was selected to match

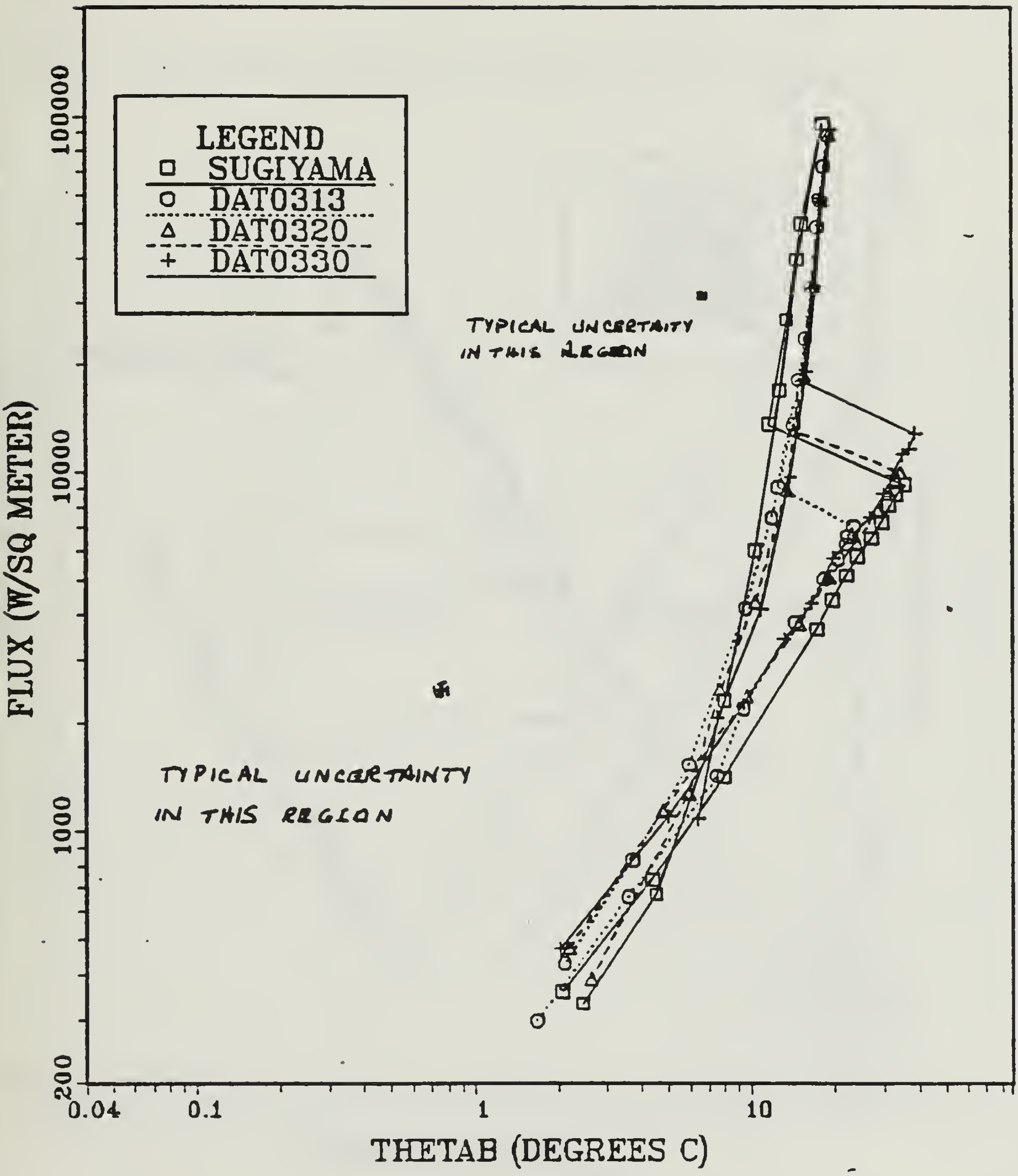

Figure 10. Repeatability Comparison for Smooth Tube, No Heat Flux on Lower Tube

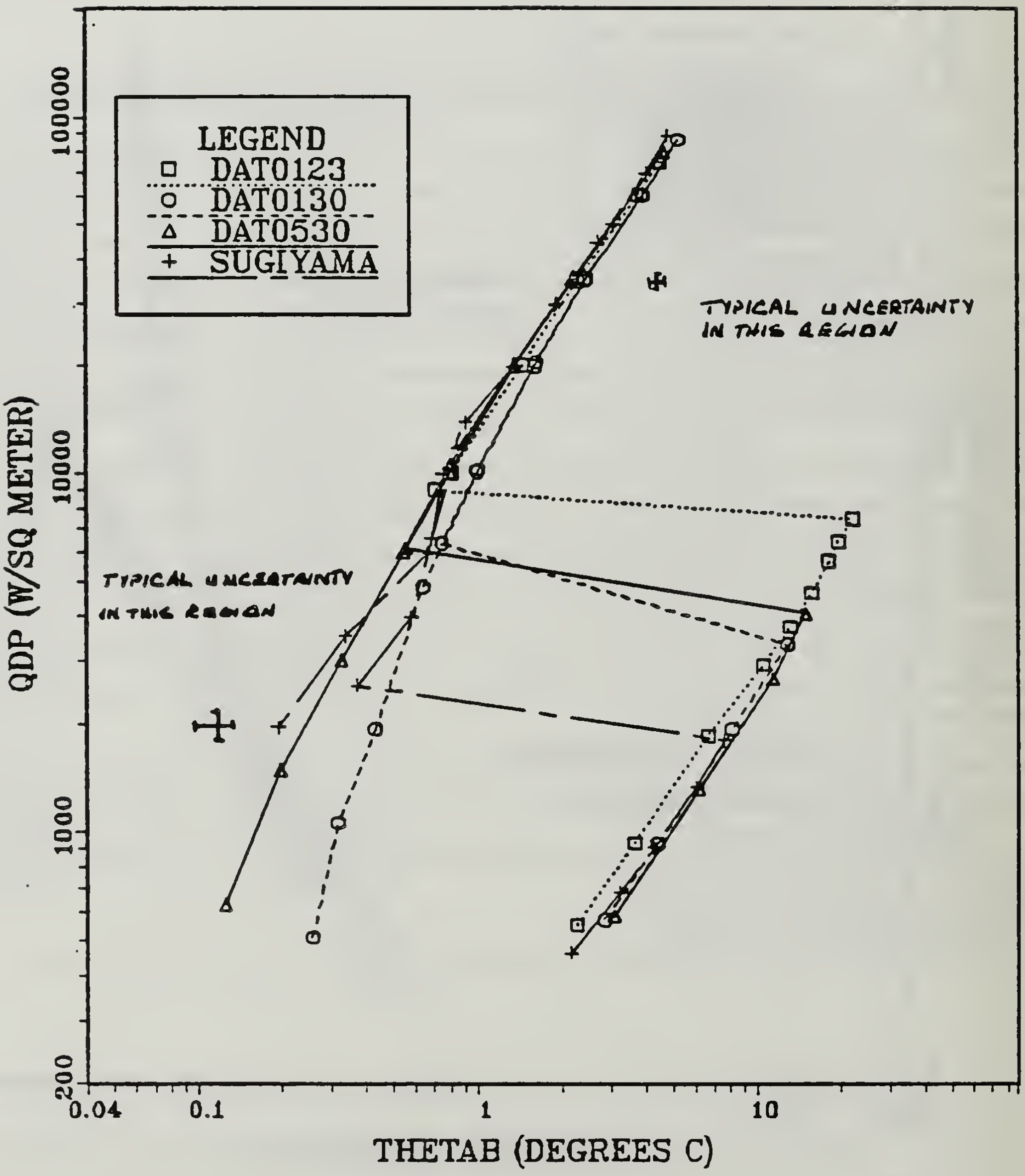

Figure 11. Repeatability Comparison for Hi Flux Tube, No Heat Flux on Lower Tube

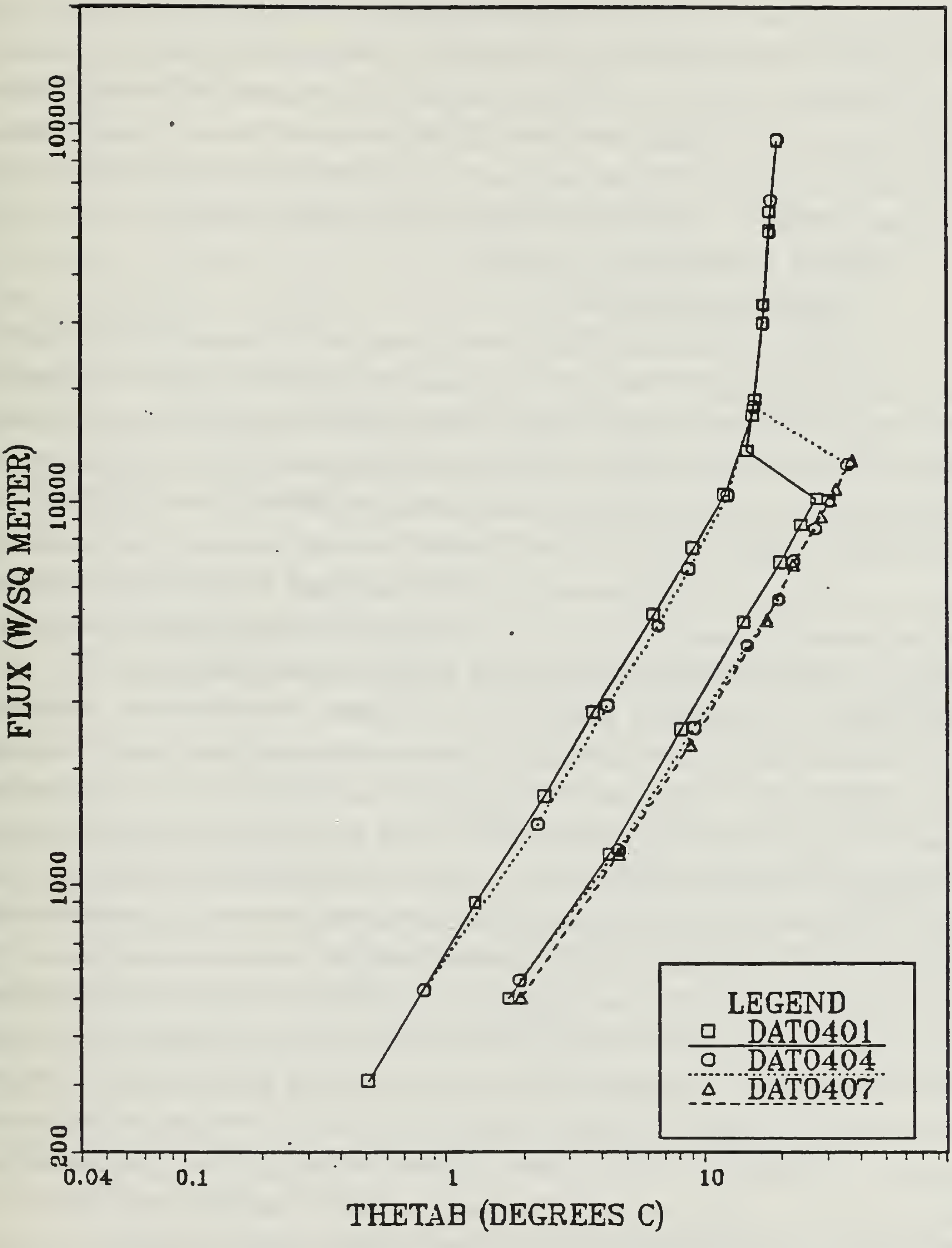

Figure 12. Repeatability Comparison for Smooth Tube, Heat Flux of 1 kW/m^2 on Lower Tube

the vertical pitch, not only in Naval centrifugal flooded evaporators, but also in the bundle apparatus in the Heat Transfer Laboratory. The fixed lower tube heat flux settings (LTHFS) used were 0, 1, 3, 10 and 25 kW/m^2 (there was one test conducted with a lower tube heat flux setting of 500 W/m^2). To evaluate the influence of the lower tube, the data has been presented in two ways: the first by common p/d ratio and the second by common LTHFS. In every case, plots of heat flux vs ΔT are shown.

1. The Effect of Heating the Lower Tube

a. *Smooth Tube p/d Ratio of 2*

Figure 13 shows data taken for a p/d ratio of 2 for the six LTHFS labeled in the legend representing kW/m^2 and CC representing the Churchill and Chu correlation [Ref. 2]. This labeling was used for all the 5 subsequent plot legends. An extra run was made at this pitch with a LTHFS of 500 W/m^2 for comparison. The natural convection regime shows very small enhancements with increasing LTHFS of up to 3 kW/m^2. Of note is that for LTHFS of 0, 0.5, 1, and 3 kW/m^2 , the lower tube was in the convection regime at the beginning of the increasing run. For the 10 and 25 kW/m^2 case the lower tube had nucleated immediately and was nucleating for the entire run. The natural convection curves are still very close to values calculated from Churchill and Chu's correlations [Ref. 2] and relatively parallel with one another. It can be seen that for a LTHFS of 500 W/m^2, the top tube behaves almost as if it were a single tube (i.e. agrees with a LTHFS of 0). In this case, the lower tube remained in the natural convection regime for the *entire* run and shows that if this is the case, little to no enhancement of the upper tube is obtained at any heat flux. The point of incipience is different for each LTHFS and proved to be a fairly random event for the smooth tubes, occurring around 12 kW/m^2. In all cases except the 0 and 500 W/m^2, the lower tube was "seeded" by bubbles from the R-114 return line (impinging upon the lower tube) when at a high flux ($> 20 kW/m^2$) on the upper tube. The lower tube then continued to nucleate after being 'seeded' throughout the remainder of the run. The LTHFS of 0, 0.5, 1 and 3 kW/m^2 showed enhancement upon nucleation, jumping to a common nucleate boiling curve. This entire run showed a very definite hysteresis effect and was very similar to Sugiyama's [Ref. 1] single tube data. Following nucleation, the four lower LTHFS followed an identical nucleate boiling curve for the remainder of the increasing run. On the decreasing run, the two lowest LTHFS showed a gradual return to the convection curve indicating a gradual deactivation of nucleation sites as heat flux was reduced on the upper tube. This coincided with no nucleation on the lower tube and also agreed well with Sugiyama's [Ref. 1] single tube results. The remaining LTHFS departed from this

curve (on the decreasing run) and showed significant enhancements (almost an order of magnitude over a single tube at the lowest heat fluxes). The enhancement increased with increasing the LTHFS until at LTHFS above 10 kW/m^2, additional enhancement was minimal. The curves followed by LTHFS greater than 1 kW/m^2 during the decreasing run were also parallel to the increasing run natural convection curves. This suggests strong convection effects on the upper tube when the lower tube is nucleating and heat flux setting on the upper tube is below 10 kW/m^2 . This agrees well with the data of Fujita *et al.* [Ref. 13]. It should be noted that all LTHFS followed the same curve above an upper tube heat flux setting of approximately 20 kW/m^2 showing no effect of LTHFS at high flux settings on the upper tube. This too is in agreement with Fujita et al.. Of particular note is that the two highest LTHFS follow the same curve for both increasing and decreasing runs, indicating complete elimination of hysteresis prominent in single tube data. The above discussion indicates a significant effect of the lower tube upon the upper tube when the lower tube is nucleating. There are almost negligible enhancements when both tubes are in the convection regime.

b. Smooth Tube p/d Ratio of 1.8.

The smooth tube runs with a p/d ratio of 1.8 , shown in Figure 14, show very similar results to that for a p/d of 2. As before for LTHFS of 0, 1 and 3 kW/m^2, both tubes begin in the convection regime for the increasing run: again no significant enhancement is seen in this region, although these curves are in better agreement with Churchill and Chu [Ref. 2]. For a given LTHFS, onset of nucleate pool boiling (ONB) occurs at different heat fluxes than in Figure 13, demonstrating the random nature of this phenomena. A common nucleate boiling curve is followed by all LTHFS runs above an upper tube heat flux setting of about 20 kW/m^2. Hysteresis effects are similar for low LTHFS as are the elimination of hysteresis for the two highest LTHFS. The lower tube was seeded by bubbles from the R-114 return line at high upper tube heat flux for all LTHFS (except 0). When compared with Figure 13, the same enhancement factors are seen at all but the highest heat fluxes, where the 1.8 p/d shows a slight enhancement over the 2 p/d. This will be shown more clearly on a later graph.

c. Smooth Tube p/d of 1.5

The same trends and enhancements seen in the previous two p/d ratios are also seen in Figure 15. LTHFS of 0, 1 and 3 are very similar to the previous two p/d ratios with no appreciable enhancement in the convection region. The lower tube started in the convection region for LTHFS of 0, 1 and 3, and was nucleating throughout for LTHFS of 10 and 25 kW/m^2 The lower tube nucleated via 'seeding' at high fluxes

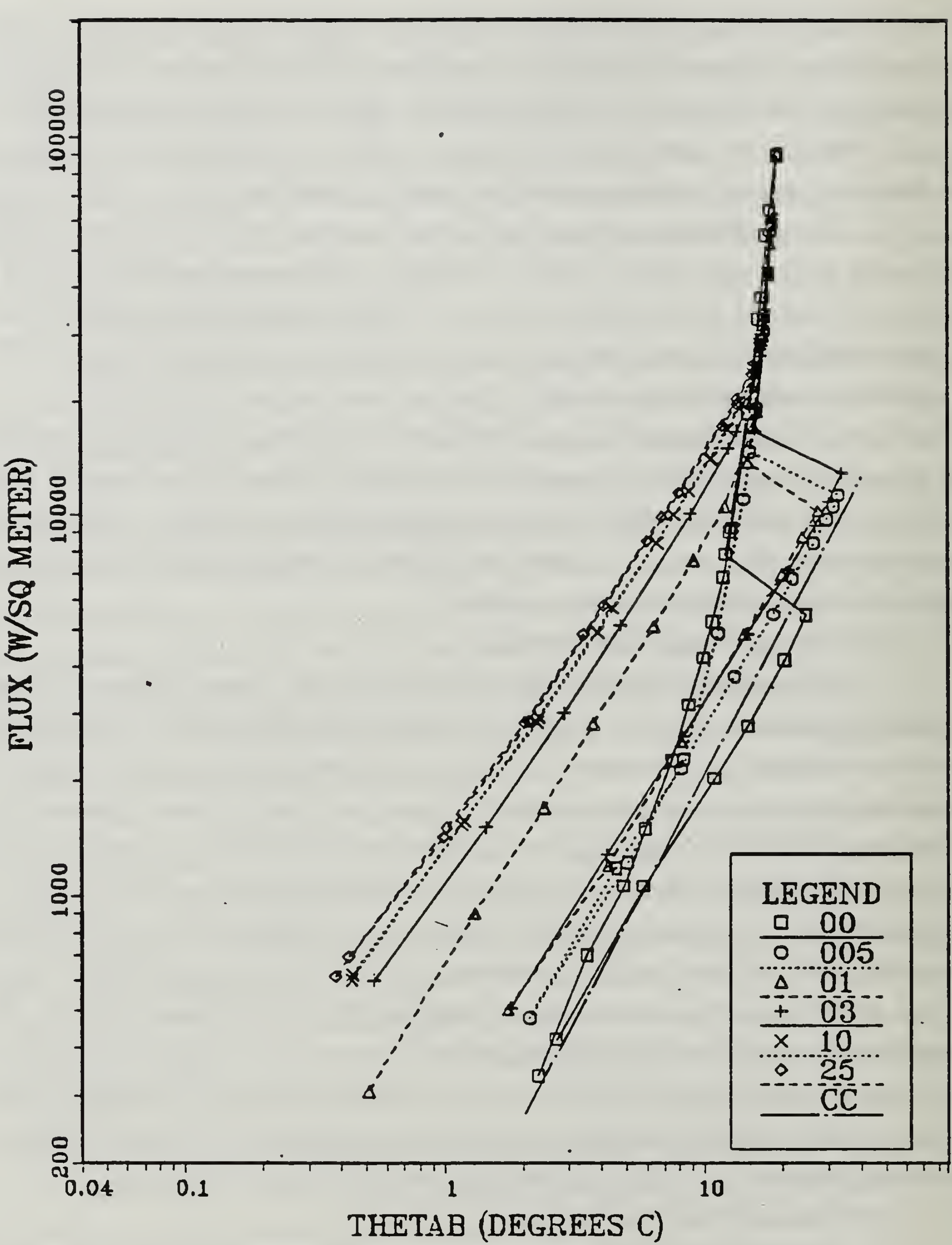

Figure 13. Comparison of Lower Tube Flux Settings for a p/d Ratio of 2 for Smooth Tube

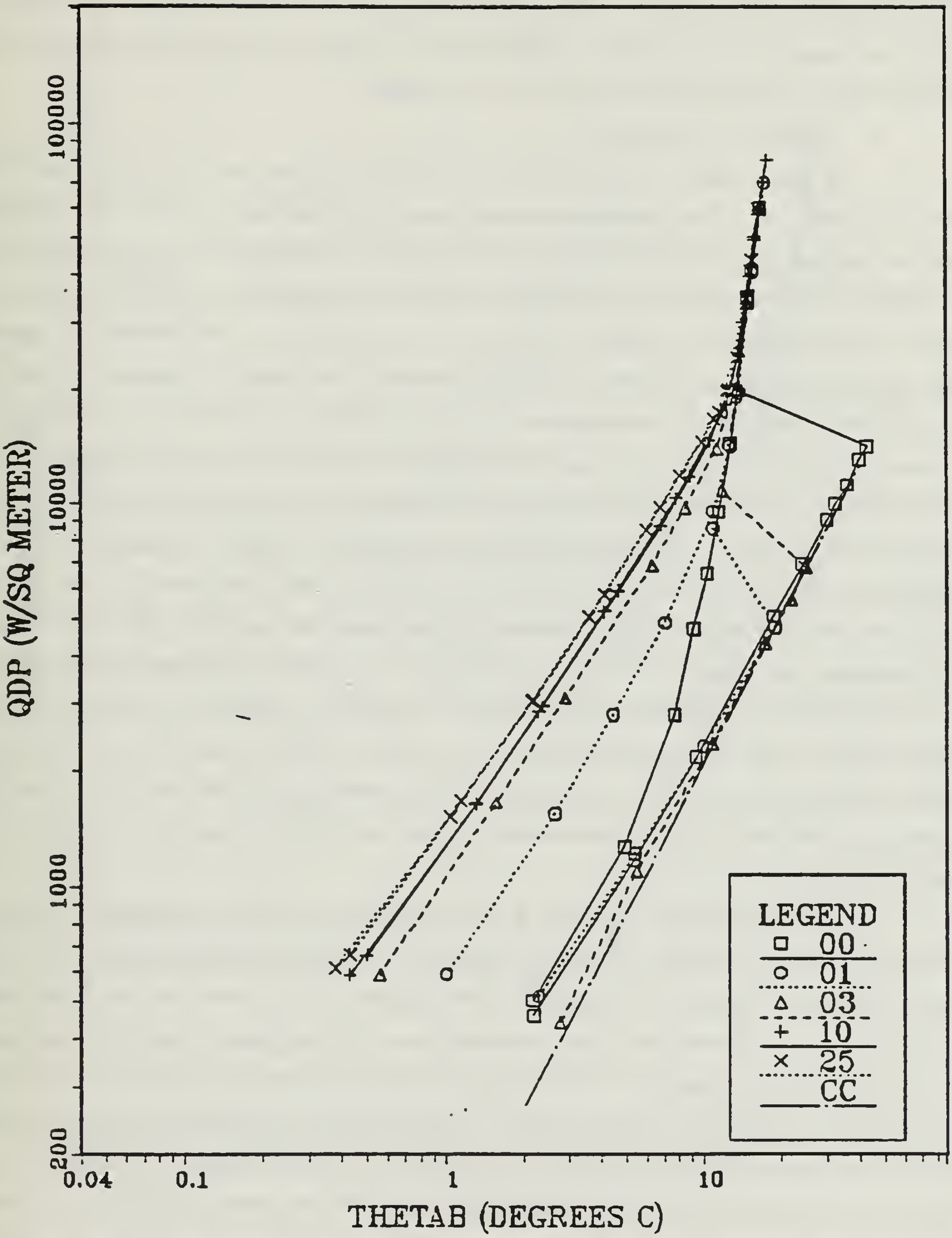

Figure 14. Comparison of Lower Tube Flux Settings for a p/d Ratio of 1.8 for Smooth Tube

on the upper tube as for the previous two p/d ratios. ONB for the upper tube continued to be a statistical phenomenon. Similar hysteresis patterns are also seen. At the highest heat flux settings, the 1.5 p/d shows a degradation compared to both the 1.8 and 2.0 p/d. This will again be shown more clearly on a later graph.

d. High Flux Tube p/d of 2

A plot of data runs made for the High Flux tube with a p/d ratio of 2 is shown in Figure 16. The convection region looks very similar to that of the smooth tubes in that they agree fairly well with Churchill and Chu [Ref. 2]. Also, there is no appreciable enhancement in the convection region for increases in LTHFS from 0 to 3 kW/m^2. For LTHFS of 0, 1 and 3, the lower tube remained in the convection regime until nucleation of the top tube, as with the smooth tube cases. However for all the High Flux tube runs, with the exception of the 0 LTHFS, the lower tube nucleated *at the same time as* the upper tube when both tubes started in the convection regime. This appeared to be due to the explosive nature of nucleation with these enhanced surfaces which caused vapor to impinge upon the lower tube thereby causing immediate nucleation on the lower tube as well; there are probably significant shock waves set up within the pool that add to this nucleation of the lower tube as well. Once the upper tube nucleated, the three LTHFS curves jumped to a common nucleate boiling curve, and demonstrated a significant temperature overshoot, similar to that found by Sugiyama [Ref. 1] for a single High Flux Tube. These LTHFS runs followed the same nucleate boiling curve for the remainder of the increasing run and for the entire decreasing run; the form of the hysteresis loop agreed very well with Sugiyama's single tube work [Ref. 1].

The lower tube nucleated from the beginning of the increasing run for a LTHFS of 10 and 25 kW/m^2. Unlike the smooth tubes, the hysteresis loop is not completely eliminated for these two LTHFS. These curves demonstrate that the upper tube experiences several effects during the increasing run. The segment of the curve between 500 and 1000 W/m^2 is parallel to the natural convection curves but well to the left (i.e. well enhanced), indicating strong convection effects due to the bubble plume from the lower tube sliding over the upper tube. This segment of the curve agrees very closely with that for the smooth tube in the convection region for the same pitch and the same LTHFS. This indicates that the bubbles sweeping over the upper non-nucleating High Flux tube have the same enhancement effect as on an upper non-nucleating smooth tube, i.e. it makes no difference which tube surface is used because the majority of the heat transfer is associated with the bubble plume sweeping over the upper tube from the

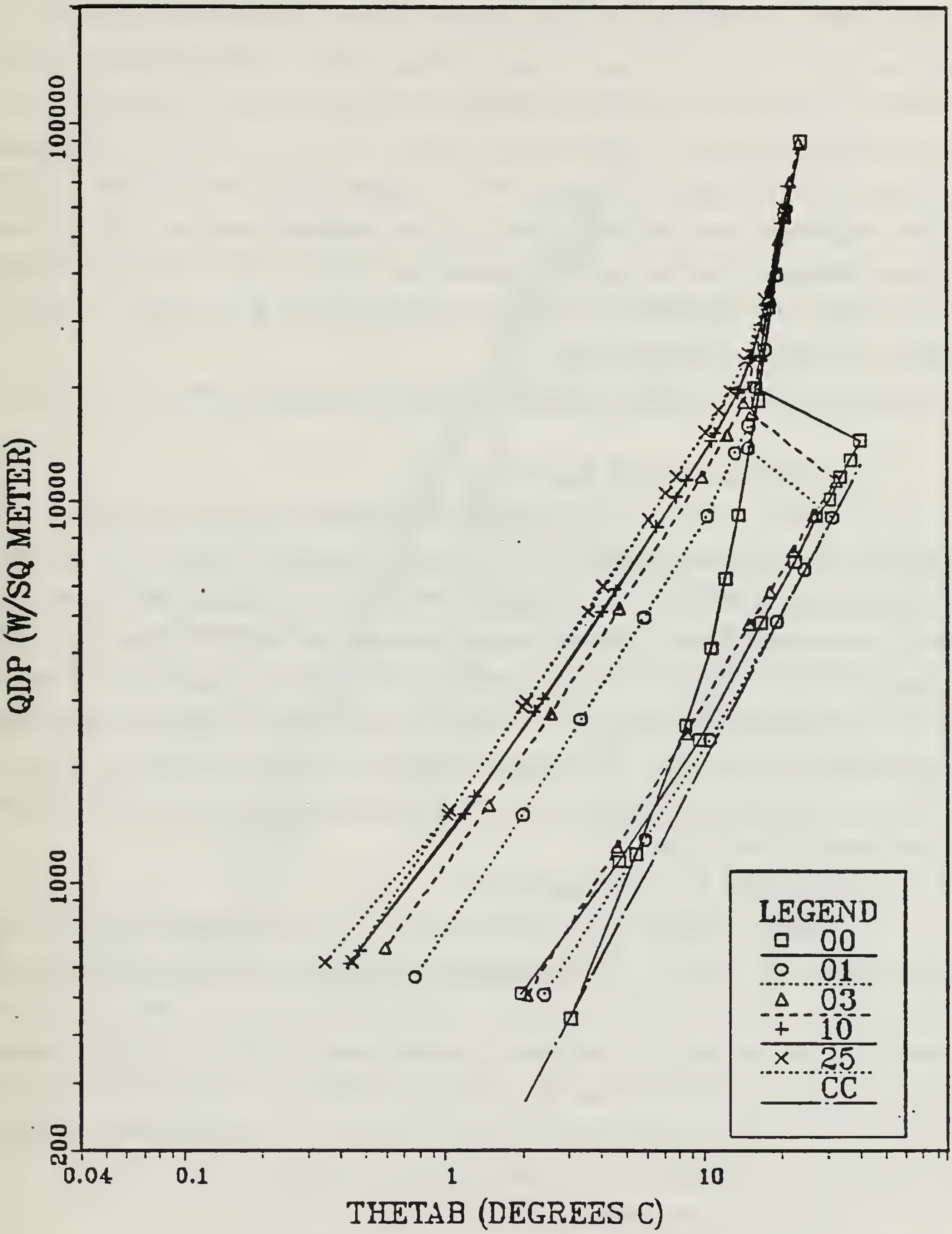

Figure 15. Comparison of Lower Tube Flux Settings for a p/d Ratio of 1.5 for Smooth Tube

nucleating tube below. This supports Cornwell's bubble sweeping hypothesis at low heat fluxes [Ref. 17]. For upper tube heat fluxes above 1000 W/m^2, the curves for both the 10 and 25 kW/m^2 LTHFS show almost vertical slopes, indicating partial nucleation and mixed convection, eventually; at high enough heat flux as they join the same common nucleate boiling curve as before with LTHFS of 0, 1 and 3 kW/m^2 All decreasing runs for all LTHFS followed the same curve, and agreed closely with both the 0 LTHFS and with single tube data (Sugiyama [Ref. 1]) for decreasing heat flux. There is some difference between the curves on the decreasing run at low fluxes; however these differences are within the experimental uncertainty which is largest in this region. The above suggests that there is no enhancement of the upper tube heat transfer coefficient gained by heating the lower tube at a p/d of 2.

e. *High Flux Tube p/d Ratio of 1.8*

Figure 17 for a p/d of 1.8 is almost identical to that for a pitch of 2. The same effects (as discussed for Figure 16 above) apply equally to Figure 17. Convection and nucleate region curves fall on top of each other with the upper tube nucleating at almost the same heat fluxes. The first segment between 500 and 1000 W/m^2 for LTHFS of 10 and 25 kW/m^2 agrees very closely with the nucleate boiling region for the smooth tube for the same pitch. The reasons for this are also discussed above, and demonstrate the repeatability of this effect. The excellent agreement between the plots in Figure 17 and Figure 16 suggests that there is no effect of tube spacing at any heat flux. This will become clearer in later figures.

f. *High Flux Tube p/d Ratio of 1.5*

Figure 18 shows the plot for a pitch of 1.5 to be almost identical to the plots for pitches of 1.8 and 2. The differences in the plot are in the same areas as in the previous pitch. The upper tube nucleates at different fluxes than in the previous two pitches, again demonstrating the somewhat random nature of ONB. In all other respects the plot is identical to the previous two, further reinforcing that there is nothing to be gained from an upper enhanced tube by the presence of a nucleating lower enhanced tube except if the upper tube is in the natural convection region.

2. The Effect of Tube Spacing

a. *Lower Tube Unheated*

To show the effect of tube spacing, plots have been made for all three pitch-to-diameter ratios at each LTHFS used. For the base of an unheated lower tube, the data are shown in Figure 19 for both the smooth and High Flux tubes for all three

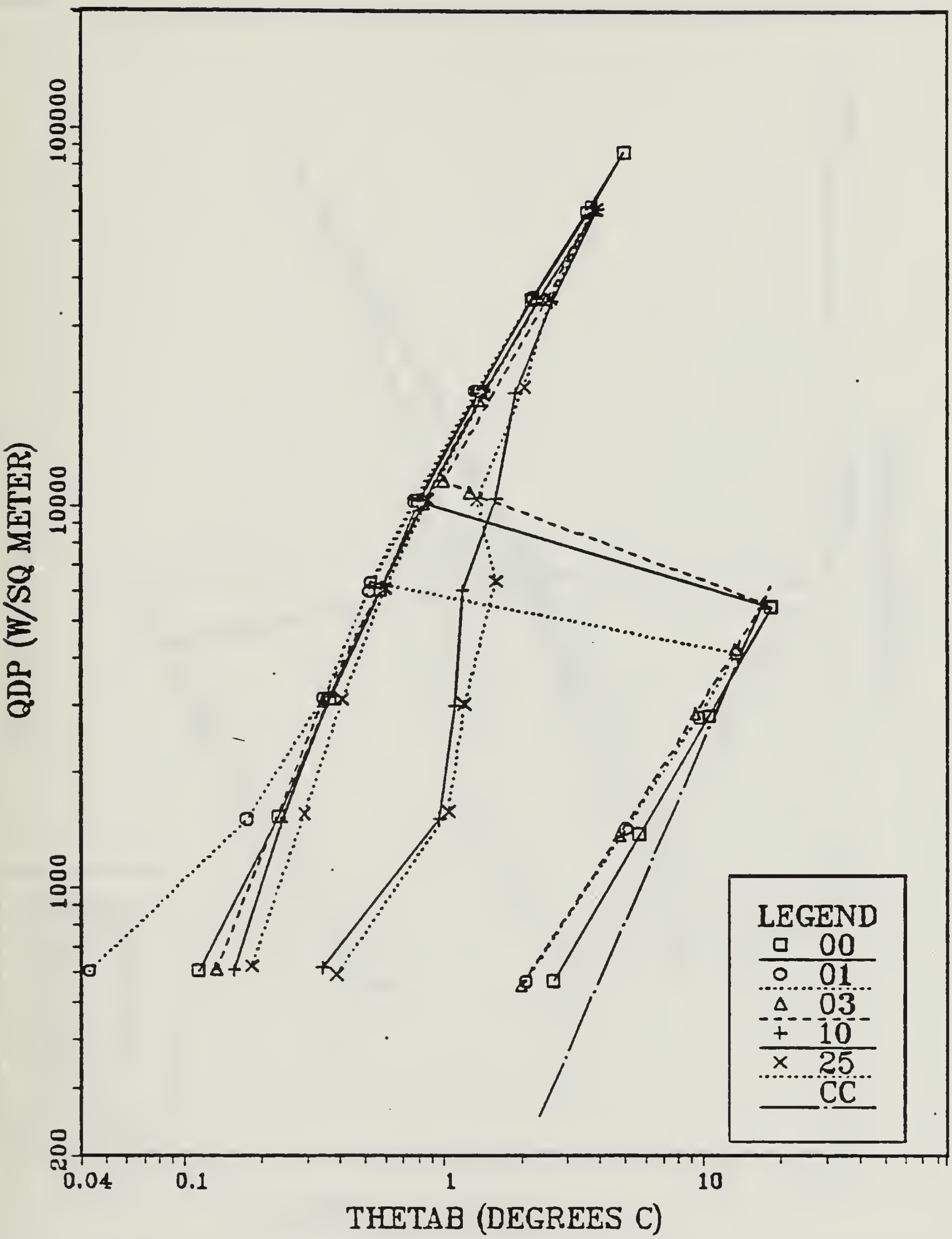

Figure 16. Comparison of Lower Tube Flux Settings for a p/d Ratio of 2 for High Flux Tube

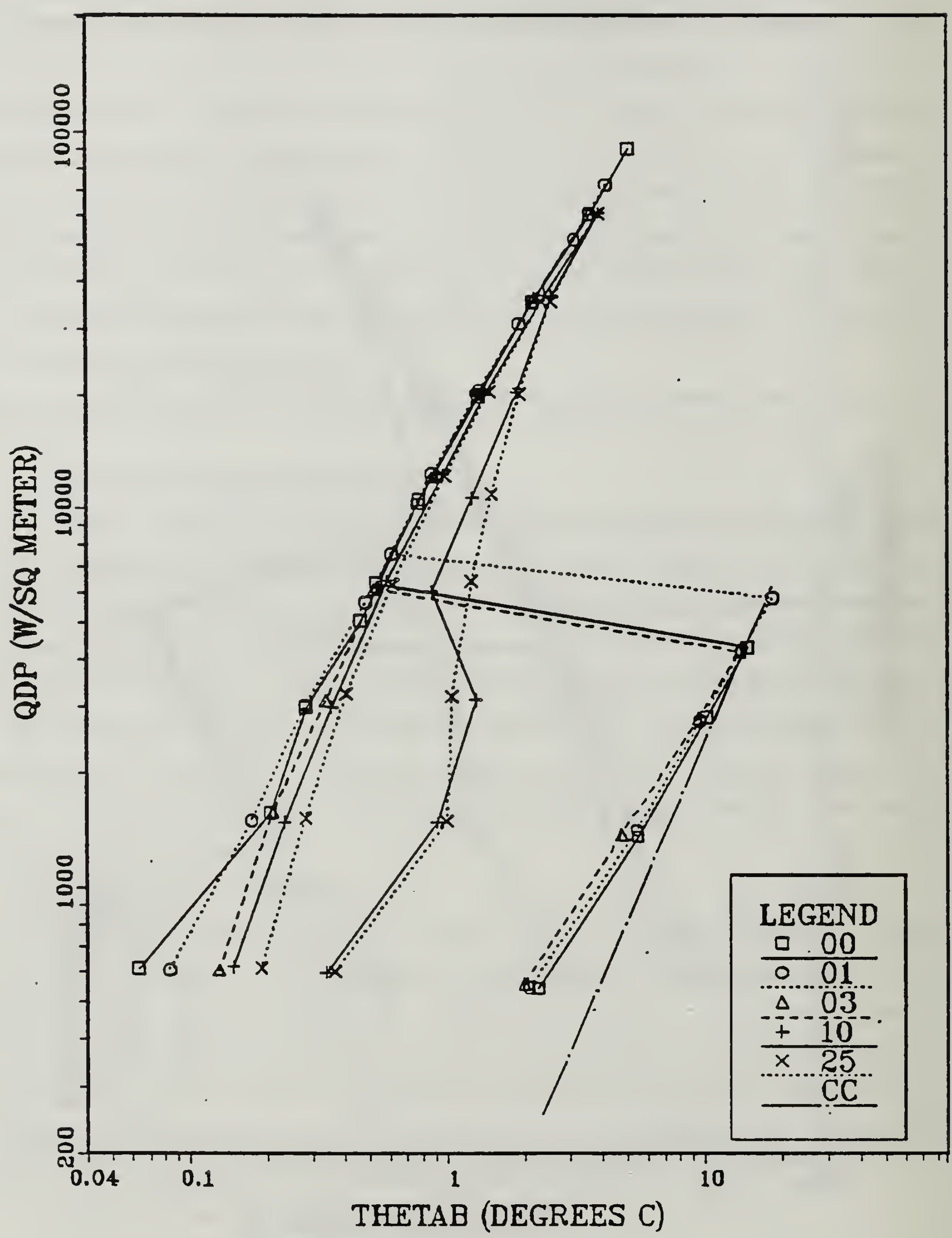

Figure 17. Comparison of Lower Tube Flux Settings for a p/d Ratio of 1.8 for High Flux Tube

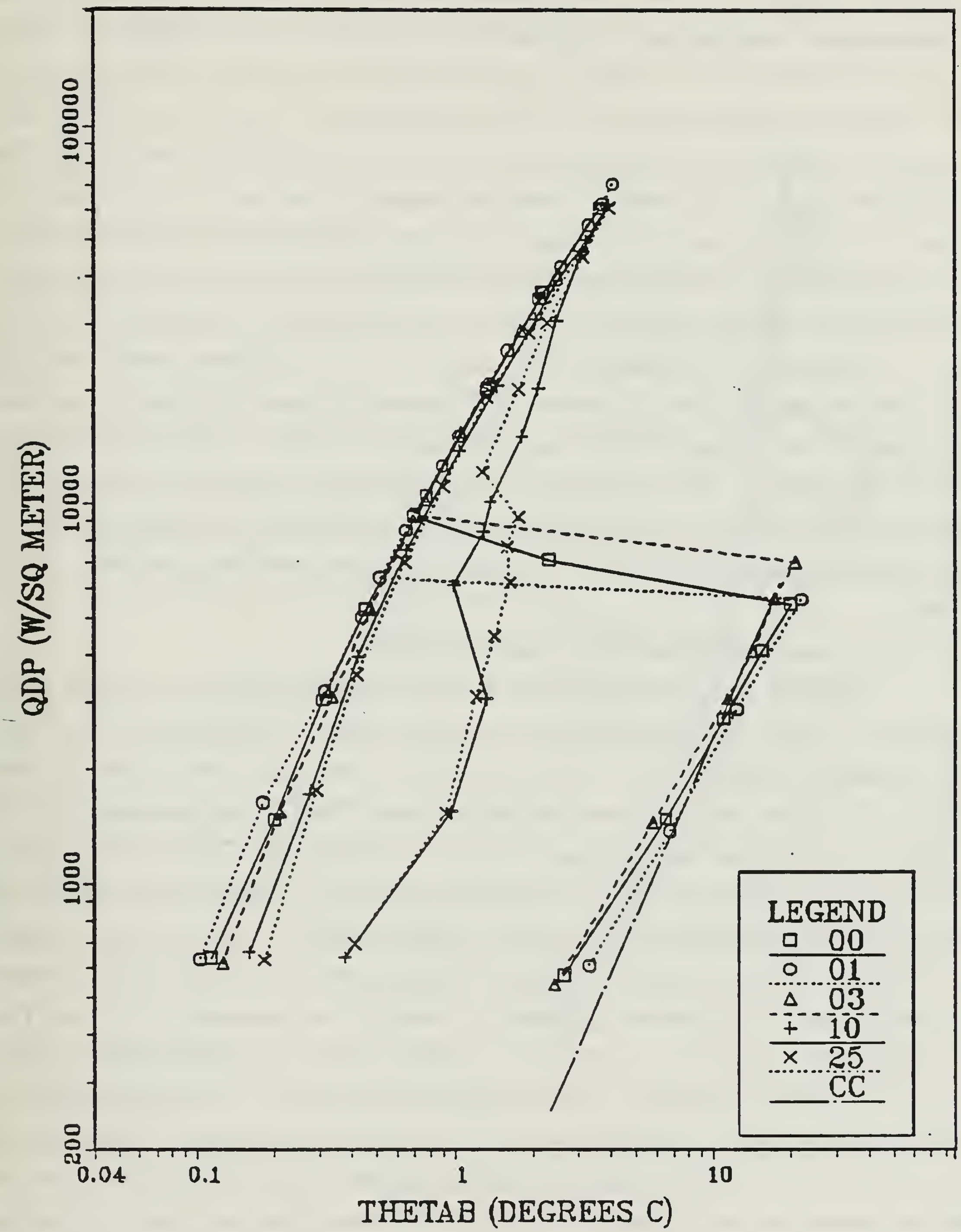

Figure 18. Comparison of Lower Tube Flux Settings for a p/d Ratio of 1.5 for High Flux Tube

values of p/d tested. This plot clearly shows the hysteresis loop for the smooth tubes (discussed earlier) and the earlier incipient point associated with the High Flux tubes. It should be noted that on a log/log plot, the temperature overshoot for the High Flux tubes looks much larger than that for the smooth tubes. In fact it is the other way around, with a smooth tube temperature overshoot of around 25 K and a High Flux value around 15 K. In the natural convection region, all the data fall very closely together. Following nucleation of the upper tube, the three curves for each tube jump to that tube's respective nucleate boiling curve for the remainder of the run; these curves agree well with Sugiyama's [Ref. 1] single tube data for both smooth and High Flux tubes. As expected for an unheated tube, there is no effect of tube spacing for High Flux tubes for any heat flux. However for the smooth tubes at high heat fluxes, there does appear to be a definite effect of tube spacing, with a p/d of 1.8 giving the best heat transfer performance. With the bottom tube unheated, it is unclear as to why this should be the case (except that its presence obviously effects the circulation patterns in the evaporator), but as will be seen, this trend is consistent even when the lower tube is heated.

b. Lower Tube Heat Flux Setting of 1 kW/m^2

Results for both tube surfaces at three values of p/d for a 1 kW/m^2 LTHFS are shown in Figure 20. In the natural convection region, it appears that both High Flux and smooth tubes show a small increasing enhancement with increasing tube spacing. This agrees with Sparrow and Niethammers [Ref. 11] and Marsters [Ref. 12] work with air. It should be noted that for this LTHFS, both upper and lower tube were in the convection region at the start of the increasing run. Figure 20 also shows the lower nucleation heat fluxes associated with ONB for High Flux tubes. Once the upper tubes nucleate, all curves 'jump' to a nucleate boiling curve. The High Flux tubes follow the same nucleate boiling curve regardless of spacing for the remainder of the run. This suggests that for a High Flux tube which is nucleating, there is no effect of heating from a lower tube with a LTHFS of 1 kW/m^2 or less for any p/d ratio. The smooth tubes on the other hand, do show small enhancements throughout the nucleate region for the three values of p/d. These are similar to the data shown in Figure 19 when the bottom tube was present but not heated, and suggests that these effects are directly related to the tube spacing itself and not due to the fact that the lower tube is heated. In Figure 20, there does seem to be some effect of p/d at these lower heat fluxes on the boiling curve; furthermore, this appears to be opposite to the trend found at high heat fluxes, i.e. a p/d of 1.5 gives the best heat transfer. However, this is thought to be ex-

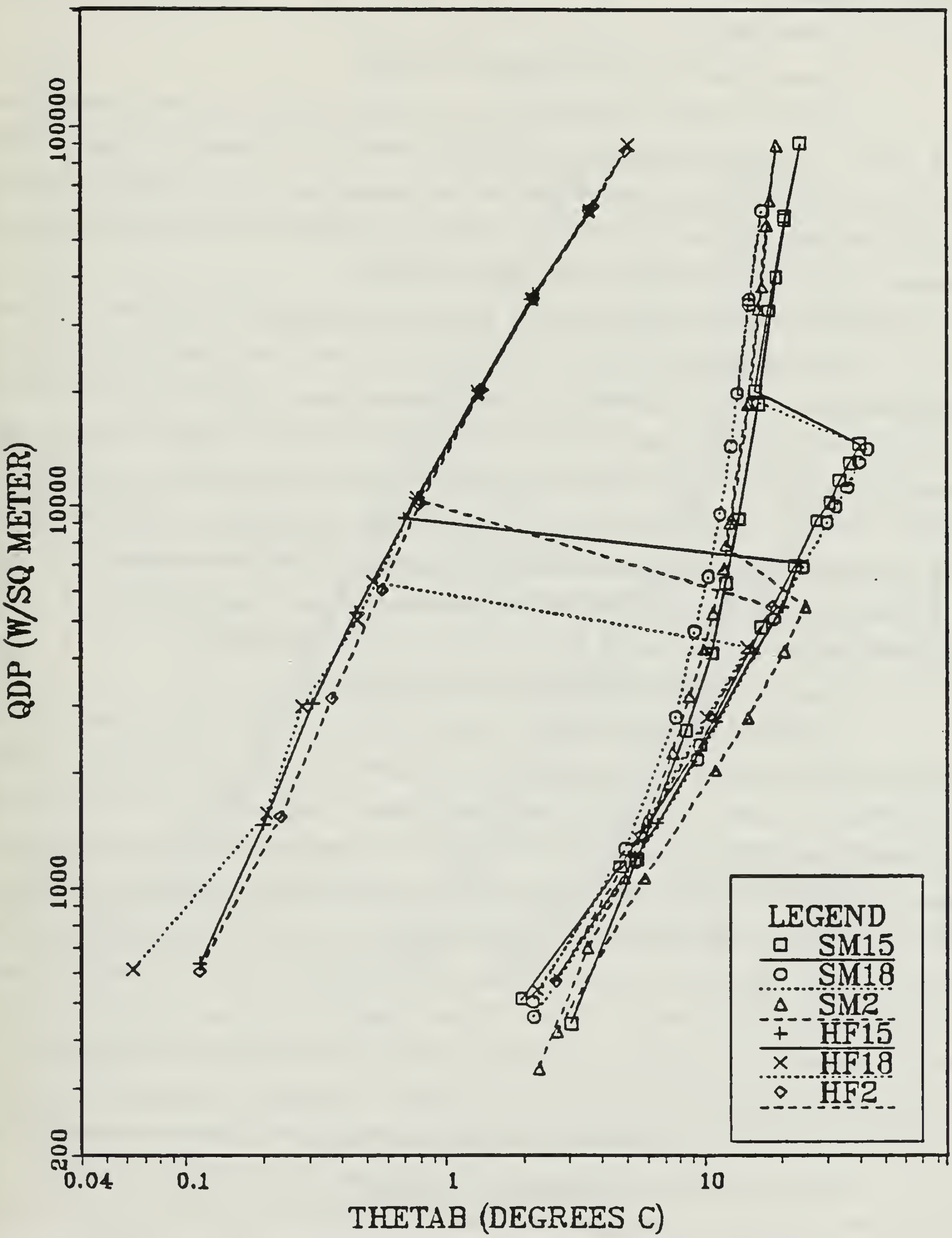

Figure 19. Comparison of Pitches for a Lower Tube Heat Flux Setting of 0 kW/m^2

perimental scatter as it does not occur on later graphs, whereas the effect at high heat fluxes is very repeatable.

c. Lower Tube Heat Flux Setting of 3 kW/m^2

The plot shown in Figure 21 for a LTHFS of 3 kW/m^2 is very similar to that for 1 kW/m^2. The same enhancement trends are seen in the convection region in that both tubes show increasing enhancement with increasing pitch, with the exception of the smooth tube with a p/d of 1.8. This is believed to be due to scatter because the performance shown for both tubes for the other LTHFS in the natural convection regime tend to follow an increasing enhancement with pitch trend. It should be noted for this LTHFS that both lower and upper tube were in the convection region at the beginning of the increasing run. Once the upper tube had nucleated, then the lower tube also started to nucleate from the 'seeding' process mentioned earlier. Following nucleation, the High Flux runs show the same results as in the previous LTHFS. The smooth tube still shows small enhancements at high heat fluxes as in the previous LTHFS, with a pitch of 1.8 giving the best enhancement. However in the boiling region below 10kW/m^2, no enhancements are discernable due to p/d (as mentioned earlier) and the curves fall directly on top of one another.

d. Lower Tube Heat Flux Setting of 10 kW/m^2

It should be noted that for this LTHFS, the lower tube nucleated at the beginning of the run and remained that way throughout the run. The plot for a LTHFS of 10 kW/m^2 is shown in Figure 22 and clearly shows the elimination of hysteresis for the smooth tube. Thus the effect of the bubbles from the lower tube sweeping over the upper tube (even when the upper tube is in the convection region) is enough to 'simulate' full nucleation from the upper tube, again supporting Cornwell's hypothesis that at low heat fluxes, the majority of the heat transfer from upper tubes in a bundle is due to convection effects from below. Figure 22 also clearly shows that there is no effect of spacing for smooth tubes except at high heat fluxes, as before (above 20 kW/m^2). For the High Flux tube it is clear that there is no effect of spacing in the decreasing portion of the curve as before. It is unclear what influence spacing may have on the increasing curve as any effects appear quite random. This suggests that the effect of spacing in this region is very small if not negligible. As mentioned earlier, the segment of the increasing High Flux curve between 500 and 1000 W/m^2 is parallel and very close to the same segment for the smooth tube curve. Note that for the smooth tube, the curve is the same for increasing and decreasing heat flux, suggesting that the top tube is not nucleating at these low heat fluxes and that the enhancement seen is due entirely to the sweeping

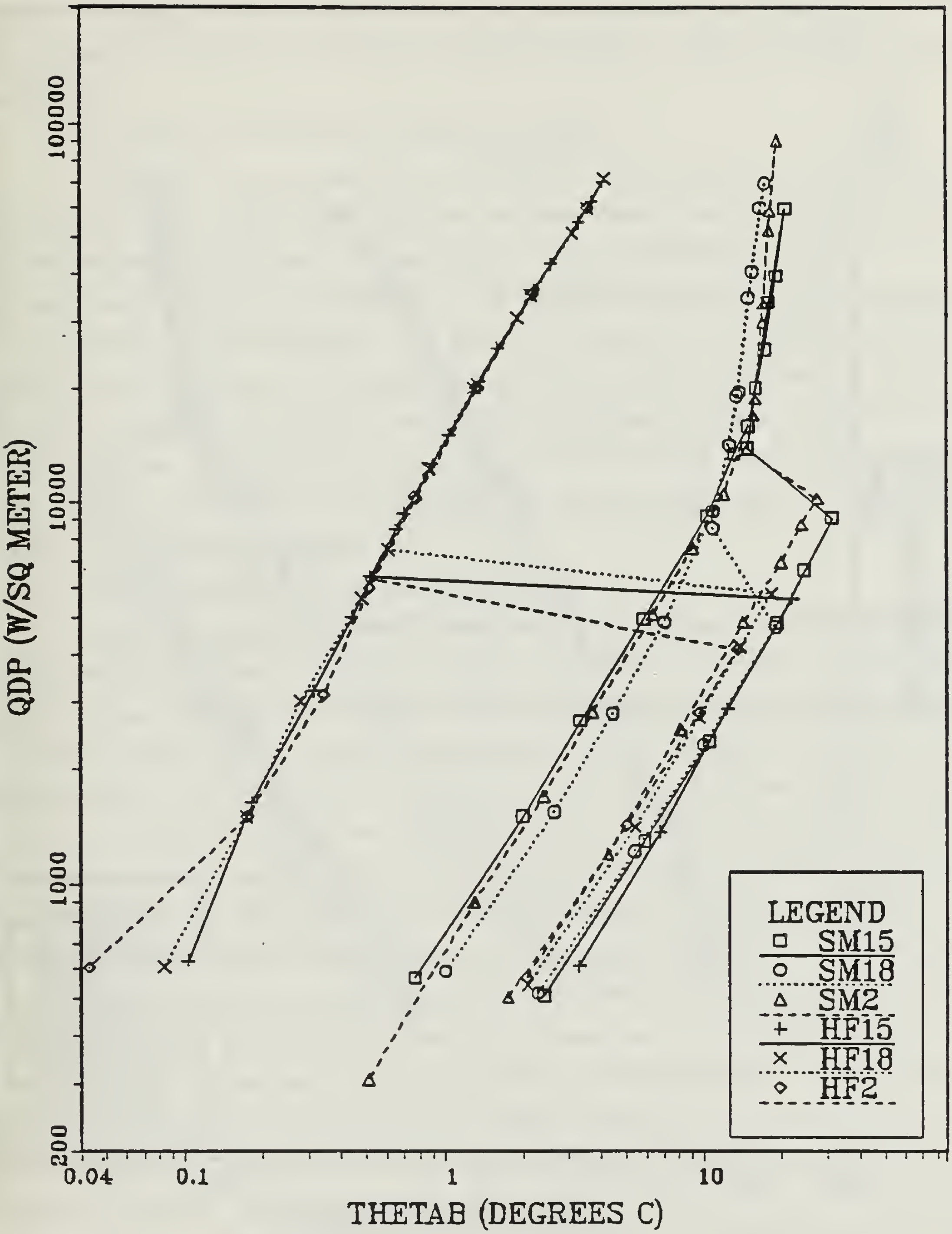

Figure 20. Comparison of Pitches for a Lower Tube Heat Flux Setting of 1 kW/m^2

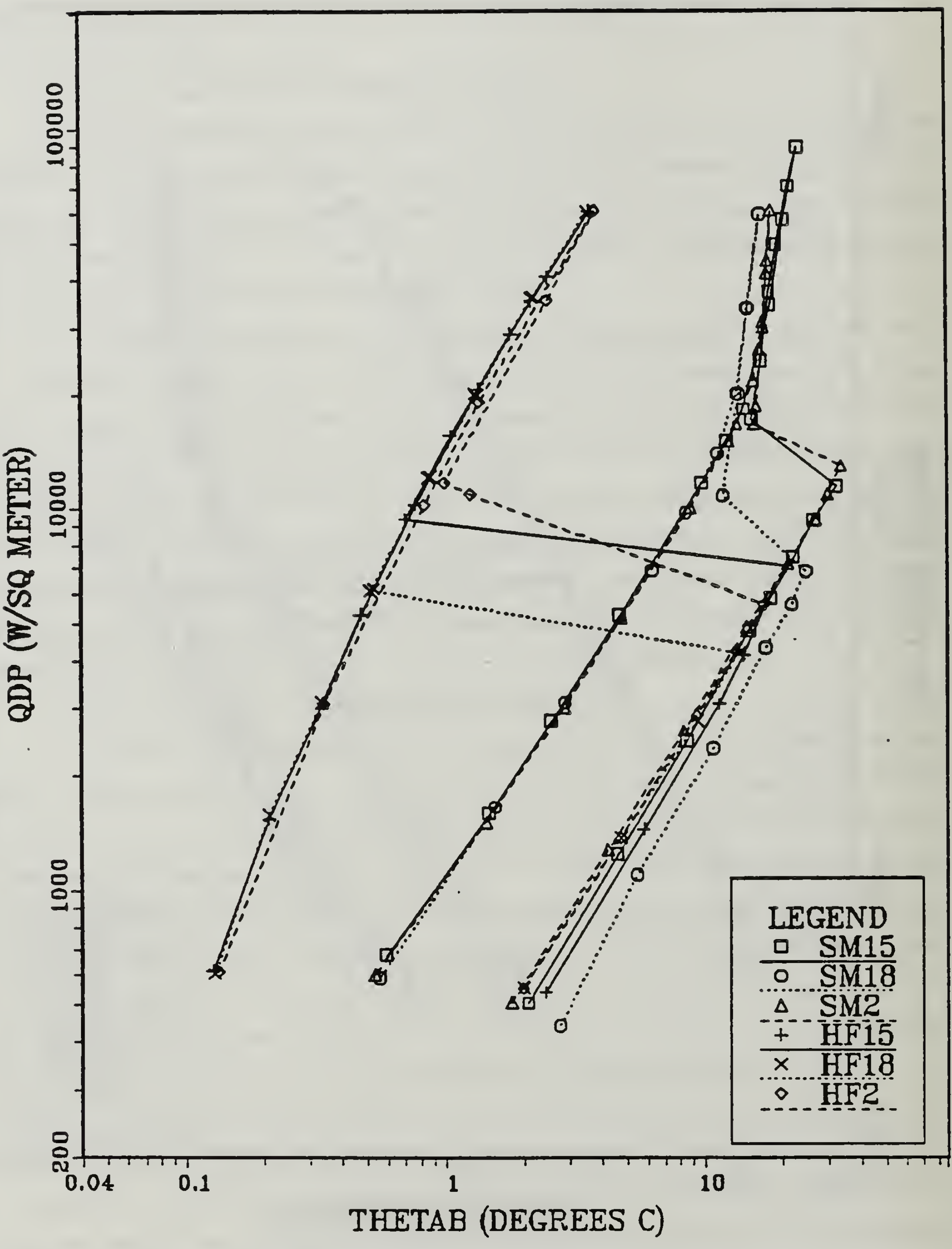

Figure 21. Comparison of Pitches for a Lower Tube Heat Flux Setting of 3 kW/m^2

bubbles from below. This implies that both tubes experience very similar convective effects when influenced by a vigorously boiling tube below. This was discussed in more detail earlier.

e. Lower Tube Heat Flux Setting of 25 kW/m^2

Figure 23 shows results for a LTHFS of 25 kW/m^2 and is very similar to that for 10 kW/m^2. It should be noted that the lower tube in each case was nucleating from the beginning of the run. The only region where spacing has any effect is in the high heat flux boiling region (above 20 kW/m^2) for the smooth tube. As in the previous case, any effects of tube spacing on the High Flux tube can be considered negligible. Again, of particular interest is the segment of the increasing curves between 500 and 1000 W/m^2. Here the curves for the smooth and High Flux tube fall on top of one another, further implyimg that at low heat fluxes (with the lower tube nucleating vigorously) the convection effects on the two types of surface are the same. Of note is the excellent repeatability of the data.

3. Both Tubes Subject To the Same Heat Flux

In addition to the data already presented, two additional runs were conducted, (one for each type of tube) in which the upper and lower tube were run up and down together at the same heat flux setting; these tests were both conducted with a p/d of 2. It should be noted that the upper and lower tubes were in the convection region at the beginning of the runs. The results of these two tests (for the upper tube only) are shown in Figure 24. The High Flux tube data fall on top of previous data, showing no effect of the lower tube throughout the entire heat flux range. This was expected due to the 'repeatability' of the High Flux tube shown in Figure 19 through Figure 23. The smooth tube shows a much earlier incipient heat flux for the upper tube. However, there is a large step in heat flux at this point due to the upper tube suddenly nucleating at a lower than expected heat flux (the cause of this nucleation is unknown and may be just a function of the randomness of this phenomenon mentioned earlier). Apart from its early ONB, the smooth tube follows a very similar boiling curve to that shown previously for a p/d of 2. At the lowest values of heat flux, the hysteresis 'loop' is still slightly open; this is because the lower tube still has a small number of active nucleation sites which are slightly enhancing the top tube. At 1 &capflux., the difference between the increasing and decreasing values of ΔT is similar to that found on Figure 20 for a LTHFS of 1 kW/m^2. This also true for the other LTHFS, i.e.the curve on Figure 24 coincides at one point with the boiling curves in Figure 19 through Figure 23 at the respective LTHFS. Of particular interest is that the foregoing results agree with and

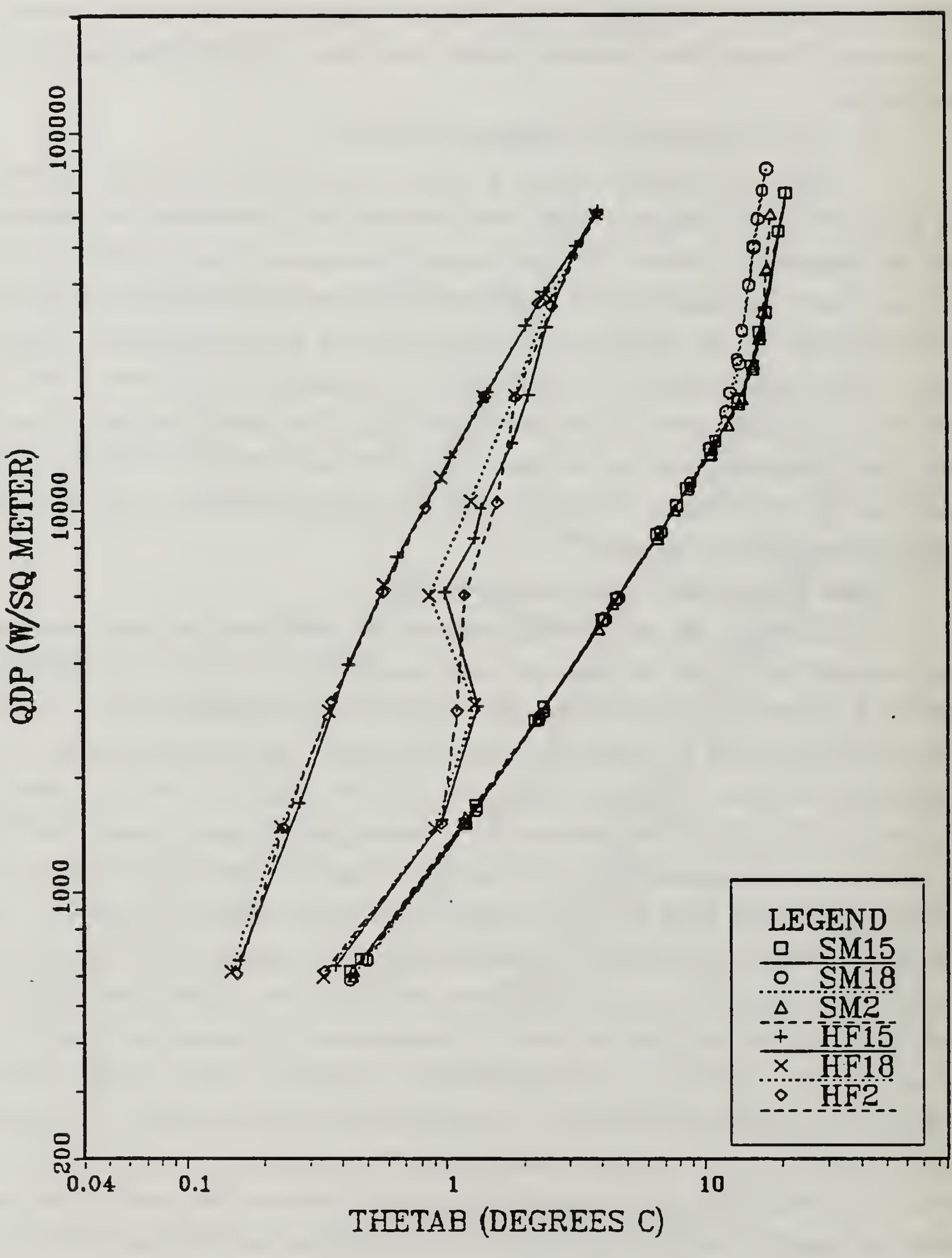

Figure 22. Comparison of Pitches for a Lower Tube Heat Flux Setting of 10 kW/m^2

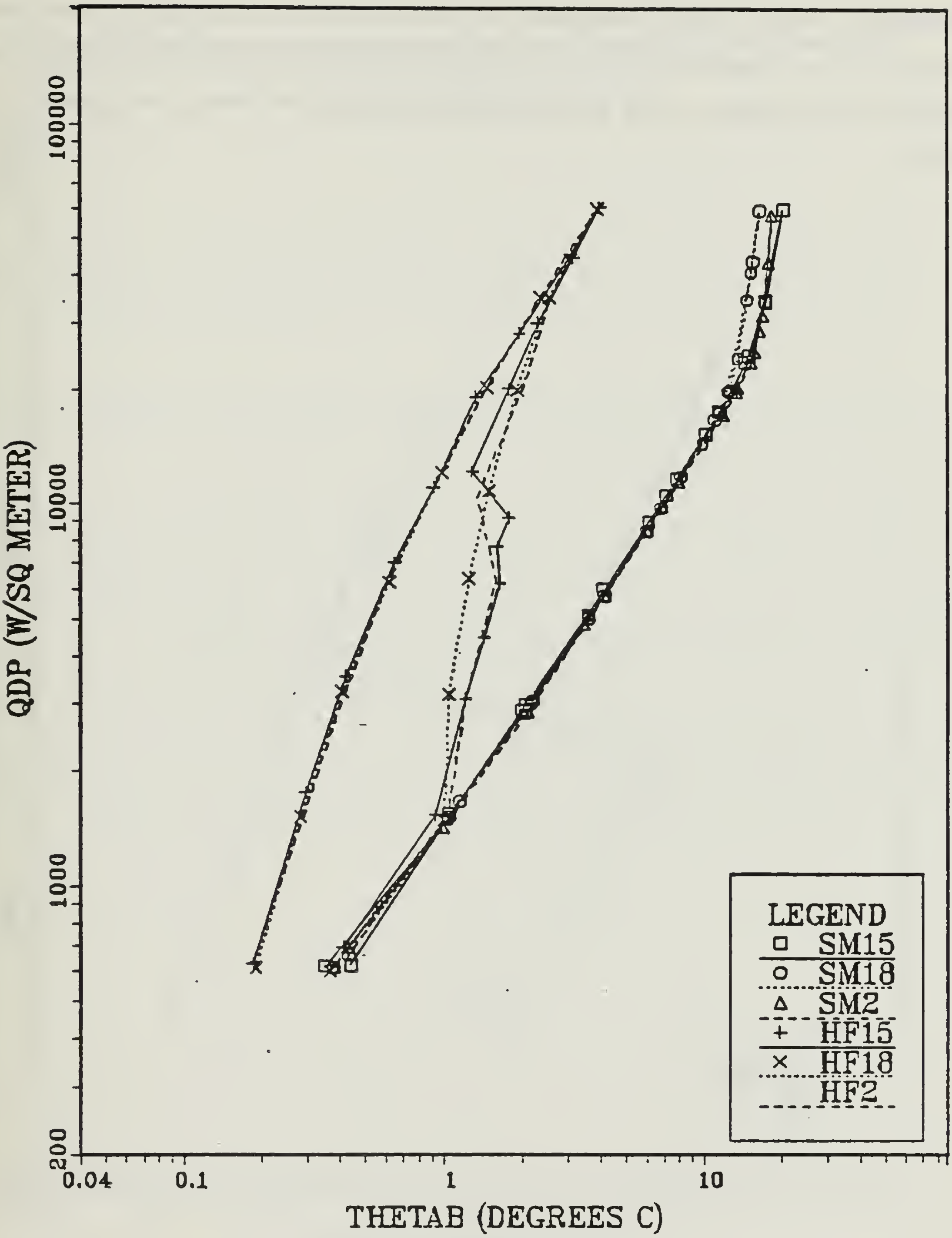

Figure 23. Comparison of Pitches for a Lower Tube Heat Flux Setting of 25 kW/m^2

complement certain results found from the bundle apparatus in the Heat Transfer laboratory. Not too many conclusions can be drawn from Figure 24 due to the lack of data taken at other spacings. This is one area which should be further investigated in the future.

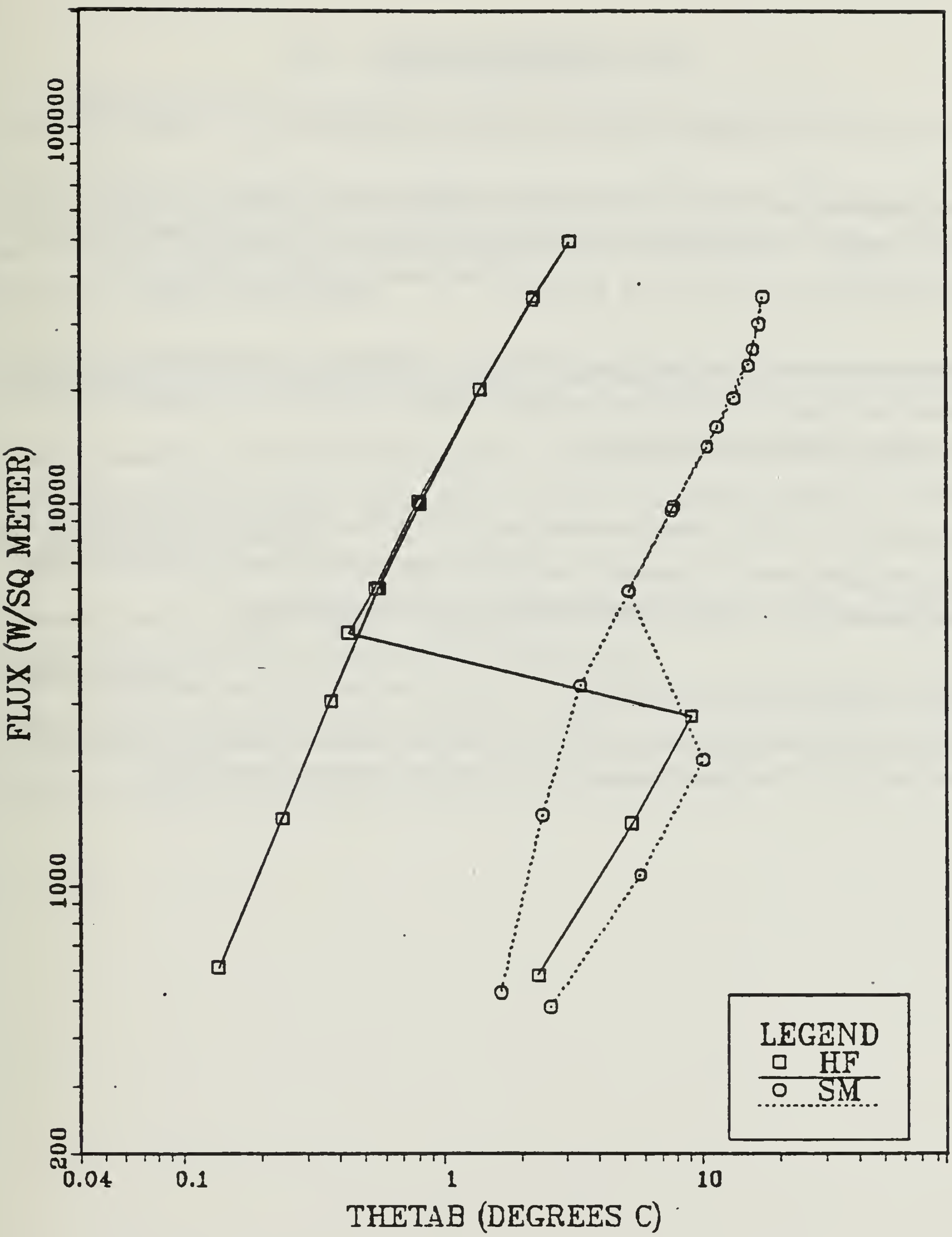

Figure 24. Comparison of Upper and Lower Tube Run Together

VI. CONCLUSIONS

1. There is no effect of tube spacing on High Flux tube performance at any heat flux.

2. The effect of tube spacing on smooth tube performance is present (but small) in the convection region. At high fluxes ($> 20\ kW/m^2$), there is a systematic dependence on tube spacing with a p/d ratio of 1.8 giving the best heat transfer performance.

3. A nucleating lower High Flux tube significantly enhances an upper High Flux tube in the convection region due to bubble sweeping. There is no effect of a heated lower tube on a nucleating upper High Flux tube.

4. A vigorously nucleating lower smooth tube ($> 10\ kW/m^2$) eliminates all hysteresis effects on an upper tube. A partially nucleating lower smooth tube ($\leq 3\ kW/m^2$) significantly enhances (by an order of magnitude) an upper smooth tube.

5. For low upper tube heat flux settings ($< 1000\ W/m^2$) and vigorous nucleation on the lower tube, High Flux and smooth tubes exhibited similar performance demonstrating that the majority of the heat transfer is due to bubble sweeping from below.

VII. RECOMMENDATIONS

1. Continue present work with other spacings and 'bundle' configurations.

2. Adapt the current apparatus to provide a larger evaporator to accommodate more than two tubes. This would probably also provide better conditions for videotaping the phenomena within the evaporator.

3. Resume experiments operating both tubes at the same heat fluxes for other spacings.

4. Pursue modeling of the enhancement effect, taking into account the mixed effects of convection (from a lower tube). Studies of a smooth tube placed above an enhanced tube might shed light on this.

5. Measurement of temperature in the plume from the lower tube to study the effect of spacing in both the natural convection and boiling region.

6. Acquisition of a Hewlett-Packard to IBM converter would greatly increase the ability to produce results from processed data within a short time frame.

APPENDIX A. SAMPLE CALCULATIONS

Data set DAT0529152 was chosen for sample calculations. The saturation temperature was 2.25 °C, the heat flux on the upper tube was 35590 W/m^2.

A. TEST-TUBE DIMENSIONS

$Do = 0.01582\ m$

$Di = 0.0132\ m$

$D1 = 0.013\ m$

$L = 0.190\ m$

$Lu = 0.076\ m$

B. MEASURED PARAMETERS

$V = 147.55\ V$

$I = 2.44\ A$

$T1 = 5.88\ °C$

$T2 = 4.90\ °C$

$T3 = 5.38\ °C$

$T4$ *not read, defective*

$T5 = 5.77\ °C$

$T6 = 7.06\ °C$

$T7 = 5.66\ °C$

$T8 = 5.48\ °C$

$Tsat = 2.25\ °C$

$kc = 45\ W/m \bullet K$

C. OUTER WALL TEMPERATURE OF THE TEST TUBE

$p = \pi \bullet Do = \pi \bullet 0.01582 = 0.0497\ m$

$$Ac = \pi(Do^2 - Di^2)/4 = \pi\{(0.01582)^2 - (0.0132)^2\}/4$$

$$Ac = 5.97 \times 10^{-5}\ m^2$$

$$Qh = VI = 145.55 \bullet 2.44 = 360.02\ W$$

$$Tavg = \sum_{1}^{m} Tn/m = 5.73\ °C$$

where m = the number of operational thermocouples used

$$Two = Tavg - Qh \bullet \{\ \ln(Do/D1)/(2 \bullet \pi \bullet L \bullet kc)\}$$

$$Two = 5.73 - 360.02\{\ \ln(\frac{0.01582}{0.01295})/(2 \bullet \pi \bullet 0.2032 \bullet 45)\}$$

$$Two = 4.48\ °C$$

$$\Theta = Two - Tsat = 4.48 - 2.25 = 2.23\ °C$$

D. PROPERTIES OF R-114 AT FILM TEMPERATURE

$Tf = (Two + Tsat)/2 = (4.48 + 2.25)/2 = 3.36\ °C$

$\mu = \exp[\,-4.4636 + (1011.47/Tf)] \cdot 10^{-3}$

$\mu = \exp[\,-4.4636 + (1011.47/(3.36 + 273.15))] \cdot 10^{-3} = 3.76 \times 10^{-4}\ N \cdot s/m^2$

$Tc = \text{Critical Temperature}(°R) = 753.95\ °R$

$Tf(°R) = 498.05\ °R$

$j = 1 - Tf(R)/Tc(R) = 1 - 498.05/753.95 = 0.34$

$\rho = 581.77 + 984.15j^{1/3} + 263.02j + 279.99j^{1/2} + 17.94j^2$

$\rho = 1522.7\ kg/m^3$

$v = \mu/\rho = 3.7605 \times 10^{-4}/1522.72 = 2.47 \times 10^{-7}\ m^2/s$

$k = 7.1 \times 10^{-2} - \{2.61 \times 10^{-4} \cdot Tf(°C)\}$

$k = 7.1 \times 10^{-2} - (2.61 \times 10^{-4} \cdot 3.36) = 7.01 \times 10^{-2}\ W/m \cdot K$

$Cp = 400 + 1.65 \cdot Tf + (1.51 \times 10^{-3} \cdot Tf^2) - (6.68 \times 10^{-7} \cdot Tf^3)$

$Cp = 959.86\ J/kg \cdot K$

$$\alpha = k/\rho \cdot Cp = 7.0224 \times \frac{10^{-2}}{1522.72 \cdot 959.856} = 4.80 \times 10^{-8}\ m^2/s$$

$$\beta = -(\Delta\rho/\Delta T)/\rho = 1.02011 \times 10^{-3}(1/K)$$

$$Pr = \nu/\alpha = 5.15$$

E. HEAT FLUX CALCULATION

Using Churchill and Chu s correlation for a cylinder in natural convection, the heat transfer coefficient from one non-boiling end can be calculated as:

$$h = \frac{k}{Do}\left[0.6 + 0.387\left\{\frac{\left(\frac{g \cdot B \cdot Do^3 \cdot \Theta \cdot \tanh(m \cdot Lu)}{\nu \cdot \alpha \cdot Lu \cdot m}\right)^{1/6}}{[1 + (0.559/Pr)^{9/16}]^{8/27}}\right\}^2\right]$$

where

$$m = \{(h \cdot p)/(kc \cdot Ac)\}^{1/2}$$

and h was computed through an iterative process beginning with an assumed h of $190 W/m^2 \cdot K$. The resulting h and m were:

$$h = 110.78\ W/m^2 \cdot K$$

$$m = 45.28$$

$$Qf = (h \cdot p \cdot kc \cdot Ac)^{1/2} \cdot \Theta \cdot \tanh(m \cdot Lu) = 0.27\ W$$

F. HEAT FLUX THROUGH ACTIVE BOILING SURFACE

$$Q = Qh - 2 \cdot Qf = 360.02 - 2(0.27) = 359.47\ W$$

$$Ab = \pi \cdot Do \cdot L = \pi \cdot 0.01582 \cdot 0.2032 = 1.01 \times 10^{-2}\ m^2$$

$$q'' = Q/Ab = 359.47/1.01 \times 10^{-2} = 35595\ W/m^2$$

$$h = q''/\Theta = 35595/2.23 = 15955\ W/m^2 \bullet K$$

The following results were produced by the data acquisition and reduction program DRP72:

$$q'' = 35590\ W/m^2$$

$$h = 15969\ W/m^2 \bullet K$$

$$\Theta = 2.23\ °C$$

The calculations were exactly the same for both tubes.

APPENDIX B. UNCERTAINTY ANALYSIS

For comparison purposes, uncertainty was determined using the same methods (those of Kline and McClintock [Ref. 18]) as Sugiyama in single tube work [Ref.1 Appendix E]. Four data points (two for the smooth tube and two for the High Flux tube) were selected for the uncertainty analysis. These points were selected such that uncertainty could be determined in the high and low heat flux regions for each tube. The points selected were data sets 19 and 35 from run DAT0529D52 and data sets 1 and 13 from run DAT0425D42. The following is a sample calculation of uncertainty for data set 19 of run DAT0529D52 (i.e. low heat flux setting on the High Flux tube). Measured and calculated parameters were obtained as in Appendix A, sample calculations. *All uncertainties are expressed as a percentage of the calculated parameter.* Results are shown in Table 5

A. UNCERTAINTY IN INPUT POWER.

$$Qh = VI$$

$Is = 0.37\ V \qquad \delta I = \pm 0.025\ A$

where δ = uncertainty in measurement and calculation

$Vs = 1.75\ V \qquad \delta V = \pm 0.05\ V$

$$I = 1.92 \bullet Is = 0.71A$$

$$V = 25 \bullet Vs = 43.78\ V$$

$$\delta Qh/Qh = \left((\delta V/Vs)^2 + (\delta I/Is)^2\right)^{1/2}$$

$$\delta Qh/Qh = \left((0.05/1.75)^2 + (0.025/0.37)^2\right)^{1/2}$$

$$\delta Qh/Qh = 7.33$$

B. UNCERTAINTY IN SURFACE AREA

$$Ab = \pi \bullet Do \bullet L$$

$$Do = 15.82mm \qquad \delta Do = 0.1mm$$

$$L = 203.20mm \qquad \delta L = 0.1mm$$

$$\delta Ab/Ab = \left((\delta Do/Do)^2 + (\delta L/L)^2\right)^{1/2}$$

$$\delta Ab/Ab = \left((0.1/15.82)^2 + (0.1/203.2)^2\right)^{1/2}$$

$$\delta Ab/Ab = 0.63$$

C. UNCERTAINTY IN WALL SUPERHEAT

$$\Delta T = Two - Tsat$$

$$Tsat = 2.27°C \qquad \delta Tsat = 0.01°C$$

$$Two = Tavg - Qh[(\ln(Do/D1))/(2 \bullet \pi \bullet L \bullet kc)]$$

$Tn =$ thermocouple readings

$$T1 = 2.76°C \qquad T2 = 2.61°C$$

$T3 = 2.67°C \qquad T4$(defective thermocouple)

$$T5 = 2.74°C \qquad T6 = 2.81°C$$

$$T7 = 2.76°C \qquad T8 = 2.74°C$$

$$Tavg = (\Sigma Tn/7)$$

where n = 1 to 3, 5 to 8

$$Tavg = 2.73°C$$

$$S.D. = ((\Sigma(Tn - Tavg)^2)/n)^{1/2} = 0.061°C$$

where S.D. = standard deviation

Compared to Tavg, the logarithmic term in the equation for Two is small and is neglected for the uncertainty analysis.

$$Two = Tavg = 2.73°C \qquad \delta Two = S.D. = 0.061°C$$

$$\Delta T = 0.37°C$$

$$\delta\Delta T/\Delta T = ((\delta Two/\Delta T)^2 + (\delta Tsat/\Delta T)^2)^{1/2}$$

$$\delta\Delta T/\Delta T = ((0.061/0.368)^2 + (0.01/0.368)^2)^{1/2}$$

$$\delta\Delta T/\Delta T = 16.8$$

D. UNCERTAINTY IN HEAT FLUX

$$q^{"} = (Qh - 2 \cdot Qf)/Ab$$

$$Qh = 31.08W \qquad \delta Qh = 2.28W$$

Assuming the same proportion in the uncertainty for Qf (losses from the unheated ends):

$$Qf = 1.6W \qquad \delta Qf = 0.12W$$

$$Qh - 2 \cdot Qf = 27.9W$$

$$\delta q^{"}/q^{"} = \{(\delta Qh/(Qh - 2 \cdot Qf))^2 + (2 \cdot Qf/(Qh - 2 \cdot Qf))^2 + (\delta Ab/Ab)^2\}^{1/2}$$

$$\delta q''/q'' = \{(2.28/27.88)^2 + (2 \cdot 0.12/27.88)^2 + (0.0063)^2\}^{1/2}$$

$$\delta q''/q'' = 8.21$$

E. UNCERTAINTY IN BOILING HEAT TRANSFER COEFFICIENT

$$h = q''/\Delta T$$

$$\delta h/h = \{(\delta q''/q)^2 + (\delta \Delta T/\Delta T)^2\}^{1/2}$$

$$\delta h/h = \{(0.0821)^2 + (0.168)^2\}^{1/2}$$

$$\delta h/h = 18.7$$

Table 5. UNCERTAINTY ANALYSIS FOR FOUR POINTS

Parameters	Smooth tube 2685 W/m^2	Smooth tube 38440 W/m^2	High Flux tube 3070 W/m^2	High Flux tube 35590 W/m^2
$\delta Qh/Qh$ (%)	7.01	1.98	7.33	2.14
$\delta Ab/Ab$ (%)	0.63	0.63	0.63	0.63
$\delta \Delta T/\Delta T$ (%)	1.91	2.52	16.8	8.08
$\delta q''/q''$ (%)	7.79	2.18	8.21	2.23
$\delta h/h$ (%)	8.02	3.33	18.7	9.40

Uncertainties listed in Table 5 show that the main source of uncertainty is in the measurement and calculation of ΔT. The uncertainty in ΔT is probably due to inaccuracies introduced during the manufacturing process. For instance, the solder pools attaching thermocouple wires to the interior sleeve may have impurities (e.g. small air gaps) which in close proximity to the thermocouple junction could affect the local heat resistance and thereby the temperature. Eight thermocouples were used to obtain the wall average and reduce this uncertainty. This also points out that further improvements in accuracy must be made in this area first. Graphical displays of uncertainty are shown in Figure 10 and Figure 11.

APPENDIX C. REPRESENTATIVE DATA SET

```
Date :     6 Apr 1992

NOTE: Program name : DRP72
      Disk number  = 00
      New file name: DAT0406I42
      TC is defective at location  5
      No defective AUX TCs exist
      Tube Number:   4

Data Set Number =   1  Bulk Oil % =  0.0
TIME:      16:09:03
TC No:     1       2       3       4       5       6       7       8
Temp :   2.61    2.62    2.64    2.62  -99.99    2.61    2.62    2.66
TC No:     9      10      11      12      13      14      15      16
Temp :  16.87   27.84   22.11   26.61   10.17   27.90   18.51   23.24
  Twa     ATwa    Tliqd    Tliqd2   Tvapr   Psat    Tsump
  2.62   21.59    2.28     2.21     2.28   -1.70   -16.5
 Thetab  Htube        Qdp            Athetab  Ahtube       AuQdp
   .356  1.716E+03  6.112E+02   19.325   5.093E+02   9.842E+03

Data Set Number =   2  Bulk Oil % =  0.0
TIME:      16:10:51
TC No:     1       2       3       4       5       6       7       8
Temp :   2.71    2.72    2.73    2.70  -99.99    2.68    2.68    2.73
TC No:     9      10      11      12      13      14      15      16
Temp :  16.87   27.86   22.10   26.60   10.15   27.89   18.46   23.21
  Twa     ATwa    Tliqd    Tliqd2   Tvapr   Psat    Tsump
  2.70   21.58    2.31     2.24     2.26   -1.69   -16.5
 Thetab  Htube        Qdp            Athetab  Ahtube       AuQdp
   .437  1.384E+03  6.048E+02   19.309   5.074E+02   9.798E+03

Data Set Number =   3  Bulk Oil % =  0.0
TIME:      16:15:44
TC No:     1       2       3       4       5       6       7       8
Temp :   3.42    3.50    3.49    3.47  -99.99    3.40    3.40    3.52
TC No:     9      10      11      12      13      14      15      16
Temp :  16.86   27.86   22.07   26.63   10.08   27.94   18.50   23.25
  Twa     ATwa    Tliqd    Tliqd2   Tvapr   Psat    Tsump
  3.45   21.58    2.28     2.21     2.24   -1.72   -16.4
 Thetab  Htube        Qdp            Athetab  Ahtube       AuQdp
  1.206  1.307E+03  1.577E+03   19.342   5.100E+02   9.864E+03

Data Set Number =   4  Bulk Oil % =  0.0
TIME:      16:16:21
TC No:     1       2       3       4       5       6       7       8
Temp :   3.43    3.52    3.51    3.48  -99.99    3.40    3.40    3.54
TC No:     9      10      11      12      13      14      15      16
Temp :  16.87   27.85   22.07   26.62   10.12   27.93   18.51   23.24
  Twa     ATwa    Tliqd    Tliqd2   Tvapr   Psat    Tsump
  3.46   21.59    2.31     2.22     2.27   -1.69   -16.4
 Thetab  Htube        Qdp            Athetab  Ahtube       AuQdp
  1.189  1.324E+03  1.574E+03   19.314   5.106E+02   9.862E+03

Data Set Number =   5  Bulk Oil % =  0.0
TIME:      16:22:00
TC No:     1       2       3       4       5       6       7       8
Temp :   4.47    4.66    4.64    4.60  -99.99    4.45    4.44    4.65
TC No:     9      10      11      12      13      14      15      16
```

```
Temp :  16.82  27.79  21.99  26.55  10.08  27.86  18.44  23.18
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat   Tsump
  4.54  21.52   2.25    2.18    2.23  -1.74  -16.3
 Thetab  Htube      Qdp          Athetab Ahtube      AuQdp
  2.321  1.270E+03  2.948E+03  19.301  5.106E+02  9.855E+03

Data Set Number =   6  Bulk Oil % =  0.0
TIME:      16:22:41
TC No:     1      2      3      4      5      6      7      8
Temp :   4.51   4.65   4.62   4.57 -99.99   4.45   4.44   4.64
TC No:     9     10     11     12     13     14     15     16
Temp :  16.81  27.78  21.98  26.55  10.06  27.86  18.45  23.17
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat   Tsump
  4.54  21.52   2.29    2.19    2.23  -1.73  -16.2
 Thetab  Htube      Qdp          Athetab Ahtube      AuQdp
  2.305  1.279E+03  2.948E+03  19.283  5.116E+02  9.865E+03

Data Set Number =   7  Bulk Oil % =  0.0
TIME:      16:27:34
TC No:     1      2      3      4      5      6      7      8
Temp :   6.63   6.95   6.89   6.82 -99.99   6.48   6.48   6.90
TC No:     9     10     11     12     13     14     15     16
Temp :  16.79  27.80  21.97  26.57  10.00  27.88  18.43  23.19
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat   Tsump
  6.70  21.51   2.27    2.19    2.20  -1.75  -16.2
 Thetab  Htube      Qdp          Athetab Ahtube      AuQdp
  4.484  1.269E+03  5.689E+03  19.296  5.113E+02  9.867E+03

Data Set Number =   8  Bulk Oil % =  0.0
TIME:      16:28:36
TC No:     1      2      3      4      5      6      7      8
Temp :   6.58   6.95   6.89   6.81 -99.99   6.55   6.55   6.95
TC No:     9     10     11     12     13     14     15     16
Temp :  16.89  27.88  22.06  26.65  10.20  27.96  18.54  23.27
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat   Tsump
  6.72  21.61   2.30    2.26    2.32  -1.66  -16.1
 Thetab  Htube      Qdp          Athetab Ahtube      AuQdp
  4.419  1.292E+03  5.709E+03  19.313  5.131E+02  9.909E+03

Data Set Number =   9  Bulk Oil % =  0.0
TIME:      16:30:19
TC No:     1      2      3      4      5      6      7      8
Temp :   6.64   6.99   6.94   6.86 -99.99   6.62   6.60   6.97
TC No:     9     10     11     12     13     14     15     16
Temp :  16.89  27.90  22.08  26.67  10.19  27.99  18.55  23.30
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat   Tsump
  6.77  21.63   2.36    2.28    2.33  -1.63  -16.1
 Thetab  Htube      Qdp          Athetab Ahtube      AuQdp
  4.443  1.285E+03  5.710E+03  19.304  5.132E+02  9.906E+03

Data Set Number =  10  Bulk Oil % =  0.0
TIME:      16:36:47
TC No:     1      2      3      4      5      6      7      8
Temp :   8.57   9.15   9.03   8.95 -99.99   8.48   8.51   9.06
TC No:     9     10     11     12     13     14     15     16
Temp :  16.90  27.82  21.99  26.59  10.03  27.90  18.44  23.21
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat   Tsump
  8.77  21.53   2.27    2.20    2.25  -1.72  -15.9
 Thetab  Htube      Qdp          Athetab Ahtube      AuQdp
  6.528  1.292E+03  8.431E+03  19.298  5.135E+02  9.904E+03
```

```
Data Set Number =  11  Bulk Oil % =  0.0
TIME:       16:37:31
TC No:      1       2       3       4       5       6       7       8
Temp :    8.67    9.15    9.07    8.96  -99.99    8.57    8.54    9.04
TC No:      9      10      11      12      13      14      15      16
Temp :   16.83   27.85   22.01   26.61   10.04   27.93   18.48   23.24
  Twa     ATwa    Tliqd    Tliqd2    Tvapr   Psat    Tsump
  8.81   21.56    2.28     2.22      2.27   -1.71   -15.9
 Thetab  Htube       Qdp            Athetab Ahtube       AuQdp
  6.549  1.298E+03  8.433E+03  19.302  5.141E+02  9.924E+03

Data Set Number =  12  Bulk Oil % =  0.0
TIME:       16:46:52
TC No:      1       2       3       4       5       6       7       8
Temp :   10.81   11.49   11.44   11.32  -99.99   10.67   10.70   11.45
TC No:      9      10      11      12      13      14      15      16
Temp :   16.85   27.92   22.03   26.67   10.02   28.00   18.49   23.28
  Twa     ATwa    Tliqd    Tliqd2    Tvapr   Psat    Tsump
 11.06   21.59    2.32     2.26      2.28   -1.67   -15.5
 Thetab  Htube       Qdp            Athetab Ahtube       AuQdp
  8.771  1.314E+03  1.152E+04  19.305  5.152E+02  9.946E+03

Data Set Number =  13  Bulk Oil % =  0.0
TIME:       16:47:44
TC No:      1       2       3       4       5       6       7       8
Temp :   10.76   11.52   11.44   11.21  -99.99   10.73   10.71   11.36
TC No:      9      10      11      12      13      14      15      16
Temp :   16.85   27.89   22.01   26.65   10.01   27.97   18.49   23.25
  Twa     ATwa    Tliqd    Tliqd2    Tvapr   Psat    Tsump
 11.03   21.57    2.32     2.24      2.27   -1.68   -15.4
 Thetab  Htube       Qdp            Athetab Ahtube       AuQdp
  8.759  1.318E+03  1.154E+04  19.296  5.166E+02  9.969E+03

Data Set Number =  14  Bulk Oil % =  0.0
TIME:       16:57:55
TC No:      1       2       3       4       5       6       7       8
Temp :   12.48   13.36   13.26   13.10  -99.99   12.29   12.30   13.19
TC No:      9      10      11      12      13      14      15      16
Temp :   16.80   27.91   21.99   26.66    9.97   27.99   18.45   23.25
  Twa     ATwa    Tliqd    Tliqd2    Tvapr   Psat    Tsump
 12.77   21.56    2.23     2.18      2.18   -1.77   -14.9
 Thetab  Htube       Qdp            Athetab Ahtube       AuQdp
 10.576  1.332E+03  1.409E+04  19.366  5.158E+02  9.989E+03

Data Set Number =  15  Bulk Oil % =  0.0
TIME:       16:58:31
TC No:      1       2       3       4       5       6       7       8
Temp :   12.40   13.36   13.29   13.14  -99.99   12.46   12.46   13.36
TC No:      9      10      11      12      13      14      15      16
Temp :   16.84   27.92   22.02   26.68   10.00   28.02   18.49   23.29
  Twa     ATwa    Tliqd    Tliqd2    Tvapr   Psat    Tsump
 12.84   21.59    2.24     2.19      2.22   -1.74   -14.8
 Thetab  Htube       Qdp            Athetab Ahtube       AuQdp
 10.619  1.330E+03  1.412E+04  19.369  5.171E+02  1.002E+04

Data Set Number =  16  Bulk Oil % =  0.0
TIME:       17:05:00
TC No:      1       2       3       4       5       6       7       8
Temp :   14.01   15.25   15.14   14.72  -99.99   14.13   14.08   15.06
```

```
TC No:      9        10        11        12        13        14        15        16
Temp :   16.84   27.94   22.04   26.69   10.02   29.02   18.49   23.26
  Twa      ATwa     Tliqd     Tliqd2   Tvapr   Psat     Tsump
 14.52   21.59    2.28      2.23      2.19   -1.74   -14.5
 Thetab   Htube          Qdp              Athetab Ahtube         AuQdp
 12.300   1.365E+03   1.679E+04   19.370   5.170E+02   1.001E+04

Data Set Number =  17  Bulk Oil % =  0.0
TIME:       17:05:42
TC No:      1         2         3         4         5         6         7         8
Temp :   14.12   15.39   15.28   14.77  -99.99   14.15   14.16   15.10
TC No:      9        10        11        12        13        14        15        16
Temp :   16.83   27.93   22.02   26.69    9.98   28.02   18.49   23.28
  Twa      ATwa     Tliqd     Tliqd2   Tvapr   Psat     Tsump
 14.61   21.59    2.27      2.18      2.20   -1.75   -14.4
 Thetab   Htube          Qdp              Athetab Ahtube         AuQdp
 12.398   1.354E+03   1.679E+04   19.376   5.154E+02   9.986E+03

Data Set Number =  18  Bulk Oil % =  0.0
TIME:       17:10:46
TC No:      1         2         3         4         5         6         7         8
Temp :   15.64   16.91   16.80   16.36  -99.99   16.07   16.01   16.72
TC No:      9        10        11        12        13        14        15        16
Temp :   16.68   27.63   21.81   26.40    9.92   27.71   18.31   23.03
  Twa      ATwa     Tliqd     Tliqd2   Tvapr   Psat     Tsump
 16.24   21.37    2.25      2.16      2.14   -1.80   -14.2
 Thetab   Htube          Qdp              Athetab Ahtube         AuQdp
 14.067   1.406E+03   1.978E+04   19.198   5.147E+02   9.881E+03

Data Set Number =  19  Bulk Oil % =  0.0
TIME:       17:11:22
TC No:      1         2         3         4         5         6         7         8
Temp :   15.54   16.84   16.73   16.36  -99.99   16.06   15.96   16.80
TC No:      9        10        11        12        13        14        15        16
Temp :   16.68   27.64   21.80   26.41    9.94   27.72   18.32   23.04
  Twa      ATwa     Tliqd     Tliqd2   Tvapr   Psat     Tsump
 16.21   21.38    2.25      2.15      2.15   -1.80   -14.1
 Thetab   Htube          Qdp              Athetab Ahtube         AuQdp
 14.036   1.407E+03   1.975E+04   19.207   5.139E+02   9.870E+03

Data Set Number =  20  Bulk Oil % =  0.0
TIME:       17:16:58
TC No:      1         2         3         4         5         6         7         8
Temp :   17.40   18.39   18.23   17.64  -99.99   17.89   17.62   18.27
TC No:      9        10        11        12        13        14        15        16
Temp :   16.77   27.72   21.88   26.50    9.98   27.79   18.39   23.08
  Twa      ATwa     Tliqd     Tliqd2   Tvapr   Psat     Tsump
 17.78   21.45    2.32      2.25      2.20   -1.72   -13.9
 Thetab   Htube          Qdp              Athetab Ahtube         AuQdp.
 15.539   1.516E+03   2.355E+04   19.206   5.148E+02   9.886E+03

Data Set Number =  21  Bulk Oil % =  0.0
TIME:       17:17:40
TC No:      1         2         3         4         5         6         7         8
Temp :   17.39   18.33   18.18   17.62  -99.99   17.82   17.64   18.24
TC No:      9        10        11        12        13        14        15        16
Temp :   16.77   27.74   21.91   26.52   10.02   27.82   18.42   23.11
  Twa      ATwa     Tliqd     Tliqd2   Tvapr   Psat     Tsump
 17.75   21.47    2.32      2.25      2.19   -1.73   -13.8
 Thetab   Htube          Qdp              Athetab Ahtube         AuQdp
```

```
 15.511  1.522E+03  2.360E+04  19.234  5.159E+02  9.923E+03

Data Set Number =  22  Bulk Oil % =  0.0
TIME:      17:23:15
TC No:     1       2       3       4       5       6       7       8
Temp :  18.56   18.95   19.94   18.14  -99.99   19.66   18.75   18.83
TC No:     9      10      11      12      13      14      15      16
Temp :  16.77   27.73   21.90   26.50   10.07   27.81   18.40   23.11
  Twa     ATwa    Tliqd    Tliqd2   Tvapr   Psat    Tsump
 18.65   21.47    2.28     2.25     2.12   -1.77   -13.5
 Thetab   Htube       Qdp          Athetab  Ahtube      AuQdp
 16.455  1.725E+03  2.838E+04  19.274  5.138E+02  9.903E+03

Data Set Number =  23  Bulk Oil % =  0.0
TIME:      17:23:57
TC No:     1       2       3       4       5       6       7       8
Temp :  18.50   18.93   18.88   18.11  -99.99   19.63   18.72   18.81
TC No:     9      10      11      12      13      14      15      16
Temp :  16.77   27.74   21.90   26.52   10.05   27.83   18.42   23.12
  Twa     ATwa    Tliqd    Tliqd2   Tvapr   Psat    Tsump
 18.63   21.48    2.28     2.22     2.12   -1.78   -13.5
 Thetab   Htube       Qdp          Athetab  Ahtube      AuQdp
 16.442  1.729E+03  2.843E+04  19.291  5.126E+02  9.889E+03

Data Set Number =  24  Bulk Oil % =  0.0
TIME:      17:29:40
TC No:     1       2       3       4       5       6       7       8
Temp :  19.09   19.38   19.33   18.42  -99.99   21.01   19.60   19.18
TC No:     9      10      11      12      13      14      15      16
Temp :  16.83   27.80   21.96   26.58   10.09   27.87   18.47   23.14
  Twa     ATwa    Tliqd    Tliqd2   Tvapr   Psat    Tsump
 19.23   21.53    2.29     2.18     2.17   -1.76   -13.1
 Thetab   Htube       Qdp          Athetab  Ahtube      AuQdp
 17.029  1.969E+03  3.353E+04  19.320  5.122E+02  9.896E+03

Data Set Number =  25  Bulk Oil % =  0.0
TIME:      17:30:27
TC No:     1       2       3       4       5       6       7       8
Temp :  19.10   19.42   19.32   18.42  -99.99   21.02   19.60   19.16
TC No:     9      10      11      12      13      14      15      16
Temp :  16.84   27.81   21.97   26.60   10.11   27.89   18.48   23.18
  Twa     ATwa    Tliqd    Tliqd2   Tvapr   Psat    Tsump
 19.24   21.54    2.32     2.21     2.19   -1.74   -13.1
 Thetab   Htube       Qdp          Athetab  Ahtube      AuQdp
 17.010  1.968E+03  3.348E+04  19.317  5.107E+02  9.865E+03

Data Set Number =  26  Bulk Oil % =  0.0
TIME:      17:35:53
TC No:     1       2       3       4       5       6       7       8
Temp :  19.60   19.79   19.81   18.74  -99.99   22.75   20.47   19.48
TC No:     9      10      11      12      13      14      15      16
Temp :  16.81   27.76   21.93   26.54   10.06   27.83   18.44   23.13
  Twa     ATwa    Tliqd    Tliqd2   Tvapr   Psat    Tsump
 19.84   21.49    2.21     2.10     2.11   -1.84   -12.7
 Thetab   Htube       Qdp          Athetab  Ahtube      AuQdp
 17.705  2.449E+03  4.335E+04  19.361  5.096E+02  9.866E+03

Data Set Number =  27  Bulk Oil % =  0.0
TIME:      17:36:50
TC No:     1       2       3       4       5       6       7       8
```

```
Temp :  19.62  19.81  19.82  18.76 -99.99  22.76  20.54  19.53
TC No:    9     10     11     12     13     14     15     16
Temp :  16.87  27.80  21.98  26.58  10.18  27.88  18.51  23.18
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat   Tsump
 19.87  21.55   2.33    2.19    2.20  -1.73  -12.6
 Thetab  Htube       Qdp         Athetab Ahtube      AuQdp
 17.639  2.456E+03  4.332E+04  19.326  5.110E+02  9.875E+03

Data Set Number =  28  Bulk Oil % =  0.0
TIME:       17:40:06
TC No:    1      2      3      4      5      6      7      8
Temp :  20.25  20.32  20.40  19.23 -99.99  24.53  21.18  20.00
TC No:    9     10     11     12     13     14     15     16
Temp :  16.89  27.83  21.99  26.60  10.17  27.91  18.53  23.22
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat   Tsump
 20.50  21.58   2.32    2.28    2.14  -1.75  -12.3
 Thetab  Htube       Qdp         Athetab Ahtube      AuQdp
 18.277  3.312E+03  6.054E+04  19.359  5.083E+02  9.839E+03

Data Set Number =  29  Bulk Oil % =  0.0
TIME:       17:40:48
TC No:    1      2      3      4      5      6      7      8
Temp :  20.23  20.30  20.38  19.22 -99.99  24.51  21.17  20.00
TC No:    9     10     11     12     13     14     15     16
Temp :  16.85. 27.74  21.93  26.51  10.13  27.82  18.47  23.15
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat   Tsump
 20.48  21.51   2.33    2.25    2.16  -1.74  -12.2
 Thetab  Htube       Qdp         Athetab Ahtube      AuQdp
 18.254  3.306E+03  6.034E+04  19.283  5.096E+02  9.826E+03

Data Set Number =  30  Bulk Oil % =  0.0
TIME:       17:41:22
TC No:    1      2      3      4      5      6      7      8
Temp :  20.23  20.31  20.38  19.22 -99.99  24.51  21.17  20.00
TC No:    9     10     11     12     13     14     15     16
Temp :  16.86  27.77  21.95  26.55  10.14  27.85  18.50  23.16
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat   Tsump
 20.48  21.53   2.30    2.27    2.13  -1.76  -12.2
 Thetab  Htube       Qdp         Athetab Ahtube      AuQdp
 18.275  3.310E+03  6.049E+04  19.323  5.100E+02  9.854E+03
NOTE: 29 data runs were stored in file DAT0406I42


Date :      6 Apr 1992

NOTE: Program name : DRP72
      Disk number  = 00
      New file name: DAT0406D42
      TC is defective at location  5
      No defective AUX TCs exist
      Tube Number:   4

Data Set Number =   1  Bulk Oil % =  0.0
TIME:       17:48:16
TC No:    1      2      3      4      5      6      7      8
Temp :  19.64  19.85  19.85  18.76 -99.99  22.85  20.54  19.54
TC No:    9     10     11     12     13     14     15     16
Temp :  16.80  27.70  21.89  26.48  10.07  27.79  18.44  23.12
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat   Tsump
 19.89  21.47   2.31    2.23    2.11  -1.78  -11.7
```

```
 Thetab   Htube       Qdp          Athetab Ahtube      AuQdp
 17.700   2.481E+03   4.392E+04   19.279   5.110E+02   9.850E+03

Data Set Number =    2  Bulk Oil % =   0.0
TIME:       17:49:07
TC No:      1       2       3       4       5       6       7       8
Temp :   19.64   19.88   19.88   18.78  -99.99   22.85   20.52   19.56
TC No:      9      10      11      12      13      14      15      16
Temp :   16.79   27.66   21.87   26.45   10.11   27.75   18.42   23.07
   Twa     ATwa    Tliqd    Tliqd2   Tvapr   Psat     Tsump
  19.90   21.45    2.32     2.28     2.14   -1.75    -11.7
 Thetab   Htube       Qdp          Athetab Ahtube      AuQdp
 17.685   2.476E+03   4.378E+04   19.231   5.112E+02   9.830E+03

Data Set Number =    3  Bulk Oil % =   0.0
TIME:       17:54:28
TC No:      1       2       3       4       5       6       7       8
Temp :   18.55   19.04   18.96   18.18  -99.99   19.76   18.77   18.87
TC No:      9      10      11      12      13      14      15      16
Temp :   16.70   27.60   21.79   26.38    9.99   27.68   18.33   23.09
   Twa     ATwa    Tliqd    Tliqd2   Tvapr   Psat     Tsump
  18.70   21.38    2.23     2.19     2.09   -1.82    -11.5
 Thetab   Htube       Qdp          Athetab Ahtube      AuQdp
 16.552   1.755E+03   2.905E+04   19.226   5.121E+02   9.845E+03

Data Set Number =    4  Bulk Oil % =   0.0
TIME:       17:55:10
TC No:      1       2       3       4       5       6       7       8
Temp :   18.61   19.05   18.96   18.17  -99.99   19.76   18.85   18.89
TC No:      9      10      11      12      13      14      15      16
Temp :   16.71   27.63   21.80   26.41    9.99   27.71   18.35   23.12
   Twa     ATwa    Tliqd    Tliqd2   Tvapr   Psat     Tsump
  18.73   21.40    2.26     2.20     2.12   -1.79    -11.5
 Thetab   Htube       Qdp          Athetab Ahtube      AuQdp
 16.551   1.756E+03   2.906E+04   19.222   5.122E+02   9.845E+03

Data Set Number =    5  Bulk Oil % =   0.0
TIME:       18:01:43
TC No:      1       2       3       4       5       6       7       8
Temp :   17.47   18.37   18.30   17.72  -99.99   17.94   17.61   18.35
TC No:      9      10      11      12      13      14      15      16
Temp :   16.70   27.60   21.78   26.39    9.96   27.67   18.32   23.07
   Twa     ATwa    Tliqd    Tliqd2   Tvapr   Psat     Tsump
  17.82   21.37    2.23     2.18     2.09   -1.83    -11.4
 Thetab   Htube       Qdp          Athetab Ahtube      AuQdp
 15.678   1.555E+03   2.439E+04   19.225   5.140E+02   9.882E+03

Data Set Number =    6  Bulk Oil % =   0.0
TIME:       18:02:25
TC No:      1       2       3       4       5       6       7       8
Temp :   17.49   18.30   18.25   17.75  -99.99   17.96   17.62   18.23
TC No:      9      10      11      12      13      14      15      16
Temp :   16.75   27.71   21.86   26.50    9.99   27.79   18.39   23.18
   Twa     ATwa    Tliqd    Tliqd2   Tvapr   Psat     Tsump
  17.80   21.45    2.25     2.22     2.10   -1.80    -11.4
 Thetab   Htube       Qdp          Athetab Ahtube      AuQdp
 15.627   1.562E+03   2.442E+04   19.295   5.153E+02   9.938E+03

Data Set Number =    7  Bulk Oil % =   0.0
TIME:       18:07:14
```

```
TC No:     1      2      3      4      5      6      7      8
Temp :  15.29  16.40  16.31  15.94 -99.99  15.69  15.53  16.35
TC No:     9     10     11     12     13     14     15     16
Temp :  16.74  27.72  21.84  26.50   9.89  27.80  18.38  23.19
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat    Tsump
 15.92  21.44   2.22    2.13    2.14  -1.81   -11.4
 Thetab  Htube      Qdp         Athetab Ahtube     AuQdp
 13.656  1.402E+03  1.915E+04  19.281  5.153E+02  9.937E+03

Data Set Number =   8  Bulk Oil % =  0.0
TIME:      18:07:50
TC No:     1      2      3      4      5      6      7      8
Temp :  15.33  16.51  16.43  15.99 -99.99  15.59  15.55  16.40
TC No:     9     10     11     12     13     14     15     16
Temp :  16.75  27.73  21.87  26.50   9.94  27.81  18.39  23.20
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat    Tsump
 15.86  21.46   2.23    2.16    2.14  -1.80   -11.4
 Thetab  Htube      Qdp         Athetab Ahtube     AuQdp
 13.690  1.397E+03  1.912E+04  19.290  5.138E+02  9.912E+03

Data Set Number =   9  Bulk Oil % =  0.0
TIME:      18:12:30
TC No:     1      2      3      4      5      6      7      8
Temp :  12.40  13.42  13.33  13.03 -99.99  12.45  12.33  13.24
TC No:     9     10     11     12     13     14     15     16
Temp :  17.23  28.71  22.91  27.44  10.37  28.81  18.97  24.02
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat    Tsump
 12.80  22.24   2.28    2.23    2.22  -1.73   -11.4
 Thetab  Htube      Qdp         Athetab Ahtube     AuQdp
 10.564  1.337E+03  1.412E+04  20.002  5.198E+02  1.040E+04

Data Set Number =  10  Bulk Oil % =  0.0
TIME:      18:13:45
TC No:     1      2      3      4      5      6      7      8
Temp :  12.22  13.34  13.25  12.95 -99.99  12.41  12.41  13.25
TC No:     9     10     11     12     13     14     15     16
Temp :  16.82  27.84  22.25  26.62  10.12  27.93  18.48  23.31
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat    Tsump
 12.75  21.60   2.27    2.18    2.20  -1.75   -11.4
 Thetab  Htube      Qdp         Athetab Ahtube     AuQdp
 10.536  1.340E+03  1.412E+04  19.392  5.143E+02  9.973E+03

Data Set Number =  11  Bulk Oil % =  0.0
TIME:      18:14:39
TC No:     1      2      3      4      5      6      7      8
Temp :  12.33  13.31  13.25  12.95 -99.99  12.39  12.36  13.24
TC No:     9     10     11     12     13     14     15     16
Temp :  16.97  27.94  22.33  26.72  10.10  28.04  18.53  23.37
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat    Tsump
 12.75  21.67   2.23    2.20    2.19  -1.76   -11.4
 Thetab  Htube      Qdp         Athetab Ahtube     AuQdp
 10.547  1.340E+03  1.413E+04  19.469  5.161E+02  1.005E+04

Data Set Number =  12  Bulk Oil % =  0.0
TIME:      18:15:27
TC No:     1      2      3      4      5      6      7      8
Temp :  12.38  13.35  13.22  13.00 -99.99  12.49  12.49  13.19
TC No:     9     10     11     12     13     14     15     16
Temp :  16.63  27.45  21.92  26.21   9.89  27.50  18.16  22.96
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat    Tsump
```

```
12.79  21.27   2.29    2.24    2.23  -1.72  -11.4
 Thetab  Htube       Qdp          Athetab Ahtube      AuQdp
 10.545  1.334E+03  1.406E+04  19.029  5.060E+02  9.628E+03

Data Set Number =  13  Bulk Oil % =  0.0
TIME:      18:20:06
TC No:     1       2       3       4       5       6       7       8
Temp :   9.58   10.38   10.34   10.11  -99.99   9.65    9.65   10.23
TC No:     9      10      11      12      13      14      15      16
Temp :  16.51   27.11   21.70   25.94   9.92   27.19   18.05   22.71
  Twa    ATwa    Tliqd   Tliqd2   Tvapr   Psat    Tsump
  9.93  21.08    2.25    2.19     2.21  -1.75  -11.5
 Thetab  Htube       Qdp          Athetab Ahtube      AuQdp
  7.718  1.297E+03  1.001E+04  18.862  5.090E+02  9.601E+03

Data Set Number =  14  Bulk Oil % =  0.0
TIME:      18:20:40
TC No:     1       2       3       4       5       6       7       8
Temp :   9.64   10.30   10.21    9.96  -99.99   9.60    9.57   10.20
TC No:     9      10      11      12      13      14      15      16
Temp :  16.49   27.08   21.68   25.90   9.91   27.16   18.04   22.69
  Twa    ATwa    Tliqd   Tliqd2   Tvapr   Psat    Tsump
  9.87  21.06    2.22    2.17     2.16  -1.79  -11.5
 Thetab  Htube       Qdp          Athetab Ahtube      AuQdp
  7.685  1.303E+03  1.001E+04  18.874  5.074E+02  9.577E+03

Data Set Number =  15  Bulk Oil % =  0.0
TIME:      18:25:06
TC No:     1       2       3       4       5       6       7       8
Temp :   6.06    6.30    6.25    6.16  -99.99   6.00    5.99    6.27
TC No:     9      10      11      12      13      14      15      16
Temp :  16.55   27.13   21.72   25.96   9.99   27.21   18.11   22.75
  Twa    ATwa    Tliqd   Tliqd2   Tvapr   Psat    Tsump
  6.12  21.11    2.24    2.20     2.23  -1.74  -11.6
 Thetab  Htube       Qdp          Athetab Ahtube      AuQdp
  3.893  1.267E+03  4.931E+03  18.889  5.062E+02  9.561E+03

Data Set Number =  16  Bulk Oil % =  0.0
TIME:      18:25:41
TC No:     1       2       3       4       5       6       7       8
Temp :   6.02    6.37    6.33    6.22  -99.99   5.98    5.99    6.32
TC No:     9      10      11      12      13      14      15      16
Temp :  16.58   27.16   21.75   25.99  10.01   27.24   18.15   22.77
  Twa    ATwa    Tliqd   Tliqd2   Tvapr   Psat    Tsump
  6.15  21.14    2.28    2.23     2.27  -1.69  -11.6
 Thetab  Htube       Qdp          Athetab Ahtube      AuQdp
  3.881  1.271E+03  4.933E+03  18.876  5.069E+02  9.567E+03

Data Set Number =  17  Bulk Oil % =  0.0
TIME:      18:30:07
TC No:     1       2       3       4       5       6       7       8
Temp :   4.46    4.65    4.63    4.56  -99.99   4.42    4.43    4.64
TC No:     9      10      11      12      13      14      15      16
Temp :  16.75   27.50   22.00   26.31  10.14   27.59   18.34   23.05
  Twa    ATwa    Tliqd   Tliqd2   Tvapr   Psat    Tsump
  4.53  21.39    2.30    2.24     2.27  -1.69  -11.7
 Thetab  Htube       Qdp          Athetab Ahtube      AuQdp
  2.255  1.268E+03  2.859E+03  19.121  5.090E+02  9.732E+03

Data Set Number =  18  Bulk Oil % =  0.0
```

```
TIME:      18:30:52
TC No:      1      2      3      4      5      6      7      8
Temp :   4.49   4.65   4.64   4.58 -99.99   4.44   4.44   4.64
TC No:      9     10     11     12     13     14     15     16
Temp :  16.75  27.48  21.98  26.30  10.11  27.57  18.33  23.05
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat    Tsump
  4.54  21.38   2.30    2.24    2.28  -1.68   -11.7
 Thetab  Htube      Qdp         Athetab Ahtube      AuQdp
  2.262  1.259E+03  2.847E+03  19.104  5.067E+02  9.681E+03

Data Set Number =  19  Bulk Oil % =  0.0
TIME:      18:35:00
TC No:      1      2      3      4      5      6      7      8
Temp :   3.39   3.46   3.46   3.42 -99.99   3.33   3.34   3.46
TC No:      9     10     11     12     13     14     15     16
Temp :  16.68  27.38  21.91  26.19  10.12  27.45  18.27  22.93
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat    Tsump
  3.40  21.30   2.25    2.20    2.22  -1.74   -11.8
 Thetab  Htube      Qdp         Athetab Ahtube      AuQdp
  1.176  1.306E+03  1.536E+03  19.079  5.060E+02  9.654E+03

Data Set Number =  20  Bulk Oil % =  0.0
TIME:      18:35:42
TC No:      1      2      3      4      5      6      7      8
Temp :   3.42   3.48   3.49   3.46 -99.99   3.37   3.38   3.50
TC No:      9     10     11     12     13     14     15     16
Temp :  16.70  27.38  21.91  26.19  10.09  27.46  18.27  22.95
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat    Tsump
  3.43  21.30   2.30    2.23    2.27  -1.69   -11.8
 Thetab  Htube      Qdp         Athetab Ahtube      AuQdp
  1.165  1.319E+03  1.537E+03  19.034  5.083E+02  9.676E+03

Data Set Number =  21  Bulk Oil % =  0.0
TIME:      18:40:25
TC No:      1      2      3      4      5      6      7      8
Temp :   2.68   2.68   2.69   2.67 -99.99   2.64   2.65   2.71
TC No:      9     10     11     12     13     14     15     16
Temp :  16.66  27.28  21.83  26.10  10.16  27.37  18.22  22.88
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat    Tsump
  2.67  21.25   2.23    2.21    2.23  -1.73   -11.9
 Thetab  Htube      Qdp         Athetab Ahtube      AuQdp
   .444  1.404E+03  6.232E+02  19.020  5.044E+02  9.593E+03

Data Set Number =  22  Bulk Oil % =  0.0
TIME:      18:41:07
TC No:      1      2      3      4      5      6      7      8
Temp :   2.71   2.71   2.73   2.70 -99.99   2.67   2.67   2.73
TC No:      9     10     11     12     13     14     15     16
Temp :  16.67  27.30  21.84  26.11  10.07  27.38  18.22  22.90
  Twa    ATwa   Tliqd   Tliqd2  Tvapr  Psat    Tsump
  2.70  21.25   2.29    2.22    2.26  -1.70   -11.9
 Thetab  Htube      Qdp         Athetab Ahtube      AuQdp
   .439  1.415E+03  6.216E+02  18.985  5.031E+02  9.551E+03
NOTE: 22 data runs were stored in file DAT0406042
```

APPENDIX D. PROGRAM SETUP72

Program SETUP72 is listed on the following pages. The program enables the user to:

1. Monitor coolant sump temperature.
2. Monitor liquid pool average temperature.
3. Monitor all thermocouple channel output temperatures.
4. Monitor voltage, current, and resulting power supplied to the upper tube heater (main heater) as well as the resistance of the heater.
5. Monitor the voltage, current, and resulting power supplied to the lower tube heater (auxiliary heater) as well as the resistance of the heater.

Program SETUP72 is written in Hewlett-Packard Basic 5.0 for the HP 9300 series computer.

```
1 !   PROGRAM: SETUP
2 !   DATE:  AUGUST 3,1991
4 !   PROGRAMMER: LT DEAN SUGIYAMA
5 !   MODIFIED BY LANNIE LAKE JAN 22, 1992
10    COM /Cc/ C(7)
20    DATA 0.10086091,25727.94399,-767345.8295,78025595.81,-9247486589,6.97688E+
11,-2.66192E+13
21    DATA 3.94078E+14
22    READ C(*)
23    ON KEY 1,15 GOTO 27
25    PRINTER IS 1
27    PRINT
29    PRINT
30    PRINT USING "4X,""SELECT OPTION"""
31    PRINT USING "6X,""0=MONITOR SUMP"""
32    PRINT USING "6X,""1=MONITOR LIQUID"""
33    PRINT USING "6X,""2=CHECK THERMOCOUPLES"""
34    PRINT USING "6X,""3=CHECK MAIN HEATER"""
35    PRINT USING "6X,""4=CHECK AUX HEATERS"""
36    PRINT USING "6X,""5=EXIT PROGRAM"""
37    PRINT USING "4X,""NOTE: KEY 1 = ESCAPE"""
39    BEEP
40    INPUT Ido
41    IF Ido>5 THEN Ido=5
42    IF Ido=0 THEN 50
43    IF Ido=1 THEN 155
44    IF Ido=2 THEN 173
45    IF Ido=3 THEN 195
46    IF Ido=4 THEN 195
47    IF Ido=5 THEN 231
49    PRINT
491
50    PRINT
51    PRINT "SUMP TEMPERATURE DEG C "
53    PRINT
54    OUTPUT 709;"AR AF19 AL19 VRS"
60    OUTPUT 709;"AS SA"
70    Sum=0
80    FOR J=1 TO 5
90    ENTER 709:E
100   Sum=Sum+E
110   NEXT J
120   Eave=Sum/5
130   Temp=FNTvsv(Eave)
140   PRINT USING "4X,MDD.DD";Temp
141   BEEP
142   PRINT
150   WAIT 5
151   GOTO 50
152!
155   PRINT
156   PRINT "LIQUID TEMPERATURE DEG C"
158   PRINT
159   OUTPUT 709;"AR AF16 AL17 VRS"
160   Sum=0
161   FOR I=1 TO 2
162   OUTPUT 709;"AS SA"
163   ENTER 709:E
164   Sum=Sum+E
```

```
165   NEXT I
166   Eave=Sum/2
167   Temp=FNTvsv(Eave)
168   PRINT USING "4X,MDD.DD";Temp
169   BEEP
170   WAIT 5
171   GOTO 155
172!
173   PRINT
175   PRINT "CHANNEL      TEMPERATURE DEG C"
177   OUTPUT 709;"AR AF00 AL19 VRS"
178   FOR I=1 TO 20
179   OUTPUT 709;"AS SA"
180   Sum=0
181   FOR J=1 TO 5
182   ENTER 709;E
183   Sum=Sum+E
184   NEXT J
185   Eave=Sum/5
186   Temp=FNTvsv(Eave)
187   PRINT TAB(3);I;TAB(15);Temp
188   NEXT I
189   BEEP
190   WAIT 5
191   GOTO 173
194!
195   PRINT
196   OUTPUT 709;"AR AF20 AL22 VRS"
197   FOR I=1 TO 3
198   OUTPUT 709;"AS SA"
199   Sum=0
200   FOR J=1 TO 5
201   ENTER 709;E
202   Sum=Sum+E
203   NEXT J
204   IF I=1 THEN Volt=Sum/5
205   IF I=2 AND Ido=3 THEN
209   PRINT "MAKE SURE VOLTAGE BOX IS SET TO MAIN HEATERS"
210   Amp=Sum/5
211   END IF
212   IF I=3 AND Ido=4 THEN
215   PRINT "MAKE SURE VOLTAGE BOX IS SET TO AUX HEATERS"
217   Amp=Sum/5
218   END IF
219   NEXT I
220   Amp=ABS(Amp*1.9182)
221   Volt=ABS(Volt*25)
222   Power=Volt*Amp
223   Resistence=Volt/Amp
224   PRINT
225   BEEP
226   PRINT "VOLTAGE(V) CURRENT(A) RESISTENCE(ohms) POWER(W)"
227   PRINT
228   PRINT USING "1X,5(MDDDD.DD,4X)";Volt,Amp,Resistence,Power
229   WAIT 5
230   GOTO 195
231   BEEP
232   PRINT
233   PRINT "THAT'S ALL FOLKS!"
234   END
```

```
235   DEF FNTvsv(V)
236   COM /Cc/ C(7)
237   T=C(0)
238   FOR I=1 TO 7
239   T=T+C(I)*V^I
240   NEXT I
241   T=T+8.626897E-2*T*(3.761199E-3-T*5.0589259E-5)
242   RETURN T
250   FNEND
```

APPENDIX E. PROGRAM DRP72

The data acquisition and reduction program DRP72 is listed on the following pages. Program DRP72 is written in Hewlett-Packard Basic 5.0 for the HP 9300 series computer.

```
10   ! FILE NAME: ORP72
20   ! DATE:        MARCH 5, 1992
30   ! REVISED VERSION OF ORP71 FOR TWO TUBE DATA
40   ! REVISED BY Lannie Lake
50     COM /Ido/ Ido
60     PRINTER IS 1
70     CALL Select
80     INPUT "WANT TO SELECT ANOTHER OPTION (1=Y,0=N)?",Isel
90     IF Isel=1 THEN GOTO 70
100    BEEP
110    BEEP
120    PRINTER IS 1
130    PRINT "DATA COLLECTION/REPROCESSING COMPLETED"
140    END
150    SUB Main
160    COM /Ido/ Ido
170    COM /Cc/ C(7),Ical
180    COM /Wi1/ O2,Di,Do,L,Lu,Kcu
190    DIM Emf(20),T(20),O1a(13),O2a(13),Dia(13),Doa(13),La(13),Lua(13),Kcua(13),
Et(19),Tn$(4)[15]
200    DATA 0.10086091,25727.94369,-767345.8295,78025595.81
210    DATA -9247486589,6.97688E+11,-2.66192E+13,3.94078E+14
220    READ C(*)
230 !  DATA "Smooth","High Flux","Thermoexel-E","Thermoexel-HE"
240    DATA Smooth,High Flux,Turbo-B,High Flux Mod,Turbo-B Mod
250    READ Tn$(*)
260    PRINTER IS 701
270    BEEP
280    IF Ido=4 THEN PRINTER IS 1
290    IF Ido=4 THEN GOTO 3030
300 !  INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Date$
310 !  OUTPUT 709;"TD";Date$
320 !  OUTPUT 709;"TD"
330 !  ENTER 709;Date$
340    PRINT
350 !  PRINT "            Month, Date and Time :";Date$
360    PRINT "            Date :",DATE$(TIMEDATE)
370    PRINT
380    PRINT USING "10X,""NOTE: Program name : ORP72"""
390    BEEP
400    INPUT "ENTER DISK NUMBER",Dn
410    PRINT USING "15X,""Disk number  = "",ZZ";Dn
420    BEEP
430    INPUT "ENTER INPUT MODE (0=3054A,1=FILE)",Im
440    BEEP
450    INPUT "1 OR 2 TUBE OPERATION (ENTER 1 OR 2)",Hwmntu
460    BEEP
470    INPUT "SELECT HEATING MODE (0=ELEC; 1=WATER)",Ihm
480    BEEP
490    INPUT "ENTER THERMOCOUPLE TYPE (0=NEW,1=OLD)",Ical
500    IF Im=0 THEN
510    BEEP
520    INPUT "GIVE A NAME FOR THE RAW DATA FILE",D2_file$
530    PRINT USING "15X,""New file name: "",14A";D2_file$
540    Size1=20
550    CREATE BDAT D2_file$,Size1
560    ASSIGN @File2 TO D2_file$
570 !
580 !  DUMMY FILE UNTIL Nrun KNOWN
```

```
590   DI_file$="DUMMY"
600   CREATE BDAT DI_file$,Size1
610   ASSIGN @File1 TO DI_file$
620   OUTPUT @File1;Date$
630   IF Ihm=0 THEN
640   BEEP
650   INPUT "ENTER NUMBER OF DEFECTIVE TCS (0=DEFAULT)",Idtc
660   IF Idtc=0 THEN
670   Ldtc1=0
680   Ldtc2=0
690   PRINT USING "16X,""No defective TCs exist"""
700   END IF
710   IF Idtc=1 THEN
720   BEEP
730   INPUT "ENTER DEFECTIVE TC LOCATION (1-8)",Ldtc1
740   PRINT USING "16X,""TC is defective at location "",DD";Ldtc1
750   Ldtc2=0
760   END IF
770   IF Idtc=2 THEN
780   BEEP
790   INPUT "ENTER DEFECTIVE TC LOCATIONS (1-8)",Ldtc1,Ldtc2
800   PRINT USING "16X,""TC are defective at locations "",DD,4X,DD";Ldtc1,Ldtc2
810   END IF
820   IF Idtc>2 THEN
830   BEEP
840   PRINTER IS 1
850   BEEP
860   PRINT "INVALID ENTRY"
870   PRINTER IS 701
880   GOTO 640
890   END IF
900   END IF
910   OUTPUT @File1;Ldtc1,Ldtc2
920   IF Humntu=1 THEN GOTO 1180
930   INPUT "ENTER NUMBER OF DEFECTIVE AUX TCS (0=DEFAULT)",Aidtc
940   IF Aidtc=0 THEN
950   Aldtc1=0
960   Aldtc2=0
970   PRINT USING "16X,""No defective AUX TCs exist"""
980   END IF
990   IF Aidtc=1 THEN
1000  BEEP
1010  INPUT "ENTER DEFECTIVE TC LOCATION (9-16)",Aldtc1
1020  PRINT USING "16X,""TC is defective at location "",DD";Aldtc1
1030  Aldtc2=0
1040  END IF
1050  IF Aidtc=2 THEN
1060  BEEP
1070  INPUT "ENTER DEFECTIVE TC LOCATIONS (9-16)",Aldtc1,Aldtc2
1080  PRINT USING "16X,""TC are defective at locations "",DD,4X,DD";Aldtc1,Aldtc
2
1090  END IF
1100  IF Aidtc>2 THEN
1110  BEEP
1120  PRINTER IS 1
1130  BEEP
1140  PRINT "INVALID ENTRY"
1150  PRINTER IS 701
1160  GOTO 940
1170  END IF
```

```
1180  OUTPUT @File1;Aldtc1,Aldtc2
1190! Im=1 option
1200  ELSE
1210  BEEP
1220  INPUT "GIVE THE NAME OF THE EXISTING DATA FILE",D2_file$
1230  PRINT USING "15X,""Old file name: "",14A";D2_file$
1240  ASSIGN @File2 TO D2_file$
1250  ENTER @File2;Nrun
1260  ENTER @File2;Dold$
1270  PRINT USING "16X,""This data set taken on : "",14A";Dold$
1280  ENTER @File2;Ldtc1,Ldtc2,Altdc1,Altdc2
1290  IF Ldtc1>0 OR Ldtc2>0 THEN
1300  PRINT USING "16X,""Thermocouples were defective at locations:"",2(3D,4X)";
Ldtc1,Ldtc2
1310  END IF
1320  IF Hwmntu=1 THEN GOTO 1350
1330  IF Aldtc1>0 OR Aldtc2>0 THEN
1340  PRINT USING "16X,""AUX Thermocouples were defective at locations:"",2(3D,4
X)";Aldtc1,Aldtc2
1350  END IF
1360  ENTER @File2;Itt
1370  END IF
1380  Idtc=0
1390  IF Ldtc1>0 THEN Idtc=Idtc+1
1400  IF Ldtc2>0 THEN Idtc=Idtc+1
1410  IF Hwmntu=1 THEN GOTO 1440
1420  IF Aldtc1>0 THEN Aidtc=Aidtc+1
1430  IF Aldtc2>0 THEN Aidtc=Aidtc+1
1440! IF Im=0 AND Ihm=1 THEN !595
1450  BEEP
1460  INPUT "WANT TO CREATE A PLOT FILE? (0=N,1=Y)",Iplot
1470  IF Iplot=1 THEN
1480  BEEP
1490  INPUT "GIVE NAME FOR PLOT FILE",P_file$
1500  CREATE BDAT P_file$,4
1510  ASSIGN @Plot TO P_file$
1520  END IF
1530  IF Ihm=1 THEN
1540  BEEP
1550  INPUT "WANT TO CREATE Uo FILE? (0=N,1=Y)",Iuf
1560  IF Iuf=1 THEN
1570  BEEP
1580  INPUT "ENTER Uo FILE NAME",Ufile$
1590  CREATE BDAT Ufile$,4
1600  ASSIGN @Ufile TO Ufile$
1610  END IF
1620  BEEP
1630  INPUT "WANT TO CREATE Re FILE? (0=N,1=Y)",Ire
1640  IF Ire=1 THEN
1650  BEEP
1660  INPUT "ENTER Re FILE NAME",Refile$
1670  CREATE BDAT Refile$,10
1680  ASSIGN @Refile TO Refile$
1690  END IF
1700  END IF
1710  PRINTER IS 1
1720  IF Im=0 THEN
1730  BEEP
1740  PRINT USING "4X,""Select tube number"""
1750  IF Ihm=0 THEN
```

```
1760  PRINT USING "5X,""0  Smooth 4 inch Ref"""
1770  PRINT USING "5X,""1  Smooth 4 inch Cu (Press/Slide)"""
1780  PRINT USING "5X,""2  Soft Solder 4 inch Cu"""
1790  PRINT USING "5X,""3  Soft Solder 4 inch HIGH FLUX"""
1800  PRINT USING "5X,""4  Wieland Hard 8 inch"""
1810  PRINT USING "5X,""5  HIGH FLUX 8 inch"""
1820  PRINT USING "6X,""6  GEWA-K 40 Fins/in"""
1830  PRINT USING "5X,""7  GEWA-K 26 Fins/in"""
1840  PRINT USING "5X,""8  GEWA-T 19 Fins/in"""
1850  PRINT USING "5X,""9  GEWA-T OR GEWA-TY 26 Fins/in"""
1860  PRINT USING "5X,""10 THERMOEXCEL-E"""
1870  PRINT USING "6X,""11 THERMOEXCEL-HE"""
1880  PRINT USING "6X,""12 TURBO-B"""
1890  PRINT USING "5X,""13 GEWA-K 19 Fins/in"""
1900  ELSE
1910  PRINT USING "6X,""0  Smooth tube"""
1920  PRINT USING "6X,""1  High Flux"""
1930  PRINT USING "5X,""2  Turbo-B"""
1940  PRINT USING "6X,""3  High Flux Mod"""
1950  PRINT USING "6X,""4  Turbo-B Mod"""
1960  END IF
1970  INPUT Itt
1980  OUTPUT @File1;Itt
1990  END IF
2000  PRINTER IS 701
2010  IF Itt<10 THEN PRINT USING "16X,""Tube Number:   "",D";Itt
2020  IF Itt>9 THEN PRINT USING "16X,""Tube Number:   "",DD";Itt
2030  IF Ihm=1 THEN PRINT USING "16X,""Tube Type:      "",15A";Tn$(Itt)
2040  BEEP
2050  INPUT "ENTER OUTPUT VERSION (0=LONG,1=SHORT,2=NONE)",Iov
2060  BEEP
2070  INPUT "SELECT (0=LIQ,1=VAP,2=(LIQ+VAP)/2)",Ilqv
2080!
2090! DIMENSIONS FO TESTED TUBES
2100! ELECTRIC HEATED MODE
2110! D1=Diameter at thermocouple positions
2120  DATA .0111125,.0111125,.0111125,.0129540,.012446,.0129540,.0100965
2130  DATA .0100965,.01157,.01157,.01157,.01157,.01157,.0100965
2140  READ D1a(*)
2150  D1=D1a(Itt)
2160!
2170! D2=Diameter of test section to the base of fins
2180  DATA .015875,.015875,.015875,.015824,.015875,.015824,.01270
2190  DATA .0127,.0138,.0138,.0138,.0138,.0138,.0127
2200  READ D2a(*)
2210!
2220! Di=Inside diameter of unenhanced ends
2230  DATA .0127,.0127,.0127,.0132,.0127,.0132,.0111125,.0111125
2240  DATA .0118,.0118,.0118,.0118,.0118,.0111125
2250  READ Dia(*)
2260!
2270! Do=Outside diameter of unenhanced ends
2280  DATA .015875,.015875,.015875,.015824,.015875,.015824,.01270,.01270
2290  DATA .01331,.01331,.01331,.01331,.0158,.0127
2300  READ Doa(*)
2310!
2320! L=Length of enhanced surface
2330  DATA .1016,.1016,.1016,.1016,.2032,.2032,.2032,.2032,.2032,.2032,.2032,.20
32,.2032,.2032
2340  READ La(*)
```

```
2350!
2360! Lu=Length of unenhanced surface at the ends
2370  DATA .0254,.0254,.0254,.0254,.0762,.0762,.0762,.0762,.0762,.0762,.0762,.07
62,.0762,.0762
2380  READ Lua(*)
2390!
2400! Kcu=Thermal Conductivity of tube
2410  DATA 399,344,344,45,344,45,344,344,399,399,399,399,399,344
2420  READ Kcua(*)
2430  IF Ihm=1 THEN
2440!
2450! Data statements for water heating mode
2460!
2470  DATA 0.015875,0.015875,0.0169,0.0139,0.0169,0,0,0,0,0
2480  READ D2a(*)
2490  DATA 0.0127,0.0127,0.0145,0.0127,0.0145,0,0,0,0,0
2500  READ Dia(*)
2510  DATA 0.015875,0.015875,0.0169,0.015875,0.0169,0,0,0,0,0
2520  READ Doa(*)
2530  DATA 0.3048,0.3048,0.3048,0.3048,0.3048,0,0,0,0,0
2540  READ La(*)
2550  DATA 0.0254,0.0254,0.0254,0.0254,0.0254,0,0,0,0,0
2560  READ Lua(*)
2570  DATA 398,45,398,45,399,0,0,0,0,0
2580  READ Kcua(*)
2590  END IF
2600  D2=D2a(Itt)
2610  Di=Dia(Itt)
2620  Do=Doa(Itt)
2630  L=La(Itt)
2640  Lu=Lua(Itt)
2650  Kcu=Kcua(Itt)
2660  Xn=.8
2670  Fr=.3
2680  IF Itt=0 THEN Cf=1.70E+9
2690  IF Itt>0 THEN Cf=3.7037E+10
2700  A=PI*(Do^2-Di^2)/4
2710  P=PI*Do
2720  IF Ihm=1 THEN
2730  BEEP
2740  INPUT "TUBE INITIATION MODE. (1=HOT WATER,2=STEAM,3=COLD WATER)",Itim
2750  IF Itim=1 THEN PRINT USING "16X,""Tube Initiate: Hot Water"""
2760  IF Itim=2 THEN PRINT USING "16X,""Tube Initiate: Steam"""
2770  IF Itim=3 THEN PRINT USING "16X,""Tube Initiate: Cold Water"""
2780  INPUT "TEMP/VEL MODE: (0=T-CONST,V-DEC;1=T-DEC,V-CONST; 2=T-INC,V-CONST)",
Itv
2790  IF Itv=0 THEN PRINT USING "16X,""Temp/Vel Mode: Constant/Decreasing"""
2800  IF Itv=1 THEN PRINT USING "16X,""Temp/Vel Mode: Decreasing/Constant"""
2810  IF Itv=2 THEN PRINT USING "16X,""Temp/Vel Mode: Increasing/Constant"""
2820  INPUT "WANT TO RUN WILSON PLOT? (1=Y,0=N)",Iwil
2830  IF Ihm=1 AND Iwil=0 THEN
2840  IF Itt=0 THEN Ci=.032
2850  IF Itt=1 OR Itt=3 THEN Ci=.059
2860  IF Itt=2 OR Itt=4 THEN Ci=.062
2870  BEEP
2880  INPUT "ENTER CI (DEF: WH=.032,HF=.059,TB=.062)",Ci
2890  PRINT USING "16X,""Sieder-Tate """
2900  PRINT USING "16X,""  Constant    = "",Z.4D";Ci
2910  END IF
2920  END IF
```

```
2930  IF Ihm=1 AND Im=1 AND Iwil=1 THEN
2940  IF Itt=0 THEN Ci=.032
2950  IF Itt=1 OR Itt=3 THEN Ci=.053
2960  IF Itt=2 OR Itt=4 THEN Ci=.062
2970  ASSIGN @File2 TO *
2980  CALL Wilson(Cf,Ci)
2990  ASSIGN @File2 TO D2_file$
3000  ENTER @File2;Nrun,Dold$,Ldtc1,Ldtc2,Itt
3010  END IF
3020  Nsub=0
3030  IF Idp=4 THEN Ihm=1
3040  IF Ihm=1 THEN Nsub=8
3050  Ntc=6
3060  IF Ihm=0 THEN Ntc=20
3070  J=1
3080  Sx=0
3090  Sy=0
3100  Sxs=0
3110  Sxy=0
3120 Repeat: !
3130  IF Im=0 THEN
3140  Otld=2.22
3150  Ido=2
3160  ON KEY 1,15 RECOVER 3120
3170  PRINTER IS 1
3180  PRINT USING "4X,""SELECT OPTION"""
3190  PRINT USING "6X,""0=TAKE DATA"""
3200  IF Ihm=0 THEN PRINT USING "6X,""1=SET HEAT FLUX"""
3210  IF Ihm=1 THEN PRINT USING "6X,""1=SET WATER FLOW RATE"""
3220  PRINT USING "6X,""2=SET Tsat"""
3230  PRINT USING "6X,""3=SET AUX HEAT FLUX"""
3240  PRINT USING "4X,""NOTE: KEY 1 = ESCAPE"""
3250  BEEP
3260  INPUT Ido
3270  IF Ido>3 THEN Ido=3
3280  IF Ido=0 THEN 5280
3290!
3300! LOOP TO SET HEAT FLUX OR FLOWMETER SETTING
3310  IF Ido=1 THEN
3320  IF Ihm=0 THEN
3330  OUTPUT 709:"AR AF20 AL21 VR5"
3340  BEEP
3350  INPUT "ENTER DESIRED Qdp",Qddo
3360  PRINT USING "4X,""DESIRED Qdp  ACTUAL Qdp"""
3370  Err=1000
3380  FOR I=1 TO 2
3390  OUTPUT 709:"AS SA"
3400  Sum=0
3410  FOR Ji=1 TO 5
3420  ENTER 709:E
3430  Sum=Sum+E
3440  NEXT Ji
3450  IF I=1 THEN Volt=Sum/5
3460  IF I=2 THEN Amp=Sum/5
3470  NEXT I
3480  Amp=ABS(Amp*1.9192)
3490  Volt=ABS(Volt*25)
3500  Aqdp=Volt*Amp/(PI*D2*L)
3510  IF ABS(Aqdp-Qddo) Err THEN
3520  IF Aqdp,Qddp THEN
```

```
3530  BEEP 4000,.2
3540  BEEP 4000,.2
3550  BEEP 4000,.2
3560  ELSE
3570  BEEP 250,.2
3580  BEEP 250,.2
3590  BEEP 250,.2
3600  END IF
3610  PRINT USING "4X,MZ.3DE,2X,MZ.3DE";Oqdp,Aqdp
3620  WAIT 2
3630  GOTO 3390
3640  ELSE
3650  BEEP
3660  PRINT USING "4X,MZ.3DE,2X,MZ.3DE";Oqdp,Aqdp
3670  Err=500
3680 ·WAIT 2
3690  GOTO 3390
3700  END IF
3710  ELSE
3720  BEEP
3730  INPUT "ENTER FLOWMETER SETTING",Fms
3740  GOTO 3190
3750  END IF
3760  END IF
3770!
3780! LOOP TO SET Tsat
3790  IF Ido=2 THEN
3800  IF Ikdt=1 THEN 3850
3810  BEEP
3820  INPUT "ENTER DESIRED Tsat",Dtld
3830! PRINT USING "4X,"" DTsat  ATsat   Rate    Tv     Rate"""
3840  Ikdt=1
3850  Old1=0
3860  Old2=0
3870  Nn=1
3880  Nrs=Nn MOD 15
3890  Nn=Nn+1
3900  IF Nrs=1 THEN
3910  IF Ihm=0 THEN PRINT USING "4X,""  Tsat      Tld1      Tld2      Tv    Tsump
"""
3920  IF Ihm=1 THEN PRINT USING "4X,""  Tsat   Tld1    Tld2    Tv   Tsump  Tinle
t   Tpile  Tout"""
3930  END IF
3940  IF Ihm=0 THEN OUTPUT 709;"AR AF16 AL19 VRS"
3950  IF Ihm=1 THEN OUTPUT 709;"AR AF0 AL5 VRS"
3960  FOR I=1 TO 5
3970  IF Ihm=0 AND I>4 THEN 4240
3980  Sum=0
3990  OUTPUT 709;"AS SA"
4000  FOR Ji=1 TO 20
4010  ENTER 709;Eliq
4020  Sum=Sum+Eliq
4030  NEXT Ji
4040  Eliq=Sum/20
4050  Tld=FNTvsv(Eliq)
4060  IF I=1 THEN Tld1=Tld
4070  IF I=2 THEN Tld2=Tld
4080  IF I=3 THEN Tv=Tld
4090  IF I=4 THEN Tsump=Tld
4100  IF I=5 THEN Tinlet=Tld
```

```
4110  IF I=5 THEN Tout=Tld
4120  NEXT I
4130  IF Ihm=1 THEN
4140  OUTPUT 709;"AR AF00 AL00 VRS"
4150  OUTPUT 709;"AS SA"
4160  Sum=0
4170  FOR Kk=1 TO 20
4180  ENTER 709:E
4190  Sum=Sum+E
4200  NEXT Kk
4210  Emf(7)=ABS(Sum/20)
4220  Tpile=Emf(7)/3.86E-4
4230  END IF
4240  Atld=(Tld1+Tld2)*.5
4250  IF ABS(Atld-Otld)>.2 THEN
4260  IF Atld>Otld THEN
4270  BEEP 4000,.2
4280  BEEP 4000,.2
4290  BEEP 4000,.2
4300  ELSE
4310  BEEP 250,.2
4320  BEEP 250,.2
4330  BEEP 250,.2
4340  END IF
4350  Err1=Atld-Old1
4360  Old1=Atld
4370  Err2=Tv-Old2
4380  Old2=Tv
4390  IF Tld1>100. THEN 4440
4400  IF Ihm=0 THEN PRINT USING "4X,5(MD00.00,2X)";Otld,Tld1,Tld2,Tv,Tsump
4410  IF Ihm=1 AND Idp=0 THEN PRINT USING "4X,7(MD0.00,2X)";Otld,Tld1,Tld2,Tv,Ts
ump,Tinlet,Tpile
4420  IF Ihm=1 AND Idp=4 THEN PRINT USING "4X,5(MD0.00,2X),3(M30.00,2X)";Otld,Tl
d1,Tld2,Tv,Tsump,Tinlet,Tpile,Tout
4430  WAIT 2
4440  GOTO 3990
4450  ELSE
4460  IF ABS(Atld-Otld)>.1 THEN
4470  IF Atld>Otld THEN
4480  BEEP 3000,.2
4490  BEEP 3000,.2
4500  ELSE
4510  BEEP 900,.2
4520  BEEP 900,.2
4530  END IF
4540  Err1=Atld-Old1
4550  Old1=Atld
4560  Err2=Tv-Old2
4570  Old2=Tv
4580  IF Ihm=0 THEN PRINT USING "4X,5(MD00.00,2X)";Otld,Tld1,Tld2,Tv,Tsump
4590  IF Ihm=1 THEN PRINT USING "4X,5(MD0.00,2X),3(M30.00,1X)";Otld,Tld1,Tld2,Tv
,Tsump,Tinlet,Tpile,Tout
4600  WAIT 2
4610  GOTO 3990
4620  ELSE
4630  BEEP
4640  Err1=Atld-Old1
4650  Old1=Atld
4660  Err2=Tv-Old2
4670  Old2=Tv
```

```
4680  IF Ihm=0 THEN PRINT USING "4X,5(MDDD.DD,2X)";Otld,Tld1,Tld2,Tv,Tsump
4690  IF Ihm=1 THEN PRINT USING "4X,9(MDD.DD,2X)";Otld,Tld1,Tld2,Tv,Tsump,Tinlet
,Tpile,Tout
4700  WAIT 2
4710  GOTO 3990
4720  END IF
4730  END IF
4740  END IF
4750  !
4760! LOOP TO SET AUX HEAT FLUX
4770  IF Ido=3 THEN
4780  IF Ihm=0 THEN
4790  PRINT " SET VOLT BOX TO AUX"
4800  OUTPUT 709;"AR AF20 AL22 VRS"
4810  BEEP
4820  INPUT "ENTER DESIRED AuQdp",Duxqdp
4830  PRINT USING "2X,""DESIRED AuxQdp  ACTUAL AuxQdp"""
4840  Err=1000
4850  FOR I=1 TO 3
4860  OUTPUT 709;"AS SA"
4870  Sum=0
4880  FOR Ji=1 TO 5
4890  ENTER 709;E
4900  Sum=Sum+E
4910  NEXT Ji
4920  IF I=1 THEN Volt=Sum/5
4930  IF I=3 THEN Amp=Sum/5
4940  NEXT I
4950  Amp=ABS(Amp*1.9182)
4960  Volt=ABS(Volt*25)
4970  Auxqdp=Volt*Amp/(PI*D2*L)
4980  IF ABS(Auxqdp-Duxqdp)>Err THEN
4990  IF Auxqdp>Duxqdp THEN
5000  BEEP 4000,.2
5010  BEEP 4000,.2
5020  BEEP 4000,.2
5030  ELSE
5040  BEEP 250,.2
5050  BEEP 250,.2
5060  BEEP 250,.2
5070  END IF
5080  PRINT USING "4X,MZ.3DE,2X,MZ.3DE";Duxqdp,Auxqdp
5090  WAIT 2
5100  GOTO 4850
5110  ELSE
5120  BEEP
5130  PRINT USING "4X,MZ.3DE,2X,MZ.3DE";Duxqdp,Auxqdp
5140  Err=500
5150  WAIT 2
5160  GOTO 4850
5170  END IF
5180  GOTO 3190
5190  END IF
5200  END IF
5210! ERROR TRAP FOR Ido OUT OF BOUNDS
5220  IF Ido<3 THEN
5230  BEEP
5240  GOTO 3190
5250  END IF
5260!
```

```
5270 ! TAKE DATA IF Im=0 LOOP
5280 IF Ikol=1 THEN 5320
5290 BEEP
5300 INPUT "ENTER BULK OIL %",Bop
5310 Ikol=1
5320 IF Ihm=0 THEN OUTPUT 709;"AR AF00 AL19 VRS"
5330 IF Ihm=1 THEN OUTPUT 709;"AR AF0 AL5 VRS"
5340 IF Ihm=0 THEN Ntc=20
5350 FOR I=1 TO Ntc
5360 OUTPUT 709;"AS SA"
5370 Sum=0
5380 FOR Ji=1 TO 20
5390 ENTER 709;E
5400 Sum=Sum+E
5410 IF I=(17-Nsub) OR I=(19-Nsub) THEN Et(Ji-1)=E
5420 NEXT Ji
5430 Kdl=0
5440 IF I=(17-Nsub) OR I=(18-Nsub) THEN
5450 Eave=Sum/20
5460 Sum=0.
5470 FOR Jk=0 TO 19
5480 IF ABS(Et(Jk)-Eave)<5.0E-6 THEN
5490 Sum=Sum+Et(Jk)
5500 ELSE
5510 Kdl=Kdl+1
5520 END IF
5530 NEXT Jk
5540 IF I=(17-Nsub) OR I=(19-Nsub) THEN PRINT USING "4X,""Kdl = "",DD";Kdl
5550 IF Kdl>10 THEN
5560 BEEP
5570 BEEP
5580 PRINT USING "4X,""Too much scattering in data - repeat data set"""
5590 GOTO 3170
5600 END IF
5610 END IF
5620 Emf(I)=Sum/(20-Kdl)
5630 NEXT I
5640 IF Ihm=1 THEN
5650 OUTPUT 709;"AR AF00 AL00 VRS"
5660 OUTPUT 709;"AS SA"
5670 Sum=0
5680 FOR Kk=1 TO 20
5690 ENTER 709;E
5700 Sum=Sum+E
5710 NEXT Kk
5720 Emf(7)=ABS(Sum)/20
5730 END IF
5740 IF Ihm=0 THEN
5750 Coun=0.
5760 OUTPUT 709;"AR AF20 AL22 VRS"
5770 FOR I=1 TO 3
5780 OUTPUT 709;"AS SA"
5790 Sum=0
5800 FOR Ji=1 TO 5
5810 ENTER 709;E
5820 Sum=Sum+E
5830 NEXT Ji
5840 IF Coun=0. THEN
5850 IF I=1 THEN Vr=Sum/5
5860 IF I=2 THEN Ir=Sum/5
```

```
5870  ELSE
5880  IF I=1 THEN Avr=Sum/5
5890  IF I=3 THEN Air=Sum/5
5900  END IF
5910  NEXT I
5920  IF Humntu=1 THEN GOTO 6010
5930  IF Coun=0 THEN
5940  PRINT "SHIFT VOLT BOX TO AUX"
5950  END IF
5960  IF Coun=1 THEN GOTO 6000
5970  INPUT "TAKE AUX READINGS(1=YES)?",Ccon
5980  Coun=Coun+Ccon
5990  GOTO 5770
6000  END IF
6010  ELSE
6020  IF Ihm=0 THEN ENTER @File2;Bop,Told$,Emf(*),Vr,Ir,Avr,Air
6030  IF Ihm=1 THEN ENTER @File2;Bop,Told$,Emf(*),Fms
6040  END IF
6050!
6060! CONVERT emf'S TO TEMP,VOLT,CURRENT
6070  Twa=0
6080  Atwa=0
6090  FOR I=1 TO Ntc
6100  IF Idtc>0 THEN
6110  IF I=Ldtc1 OR I=Ldtc2 THEN
6120  T(I)=-99.99
6130  GOTO 6300
6140  END IF
6150  END IF
6160  IF Hwmntu=1 THEN GOTO 6230
6170  IF Aidtc>0 THEN
6180  IF I=Aldtc1 OR I=Aldtc2 THEN
6190  T(I)=-99.99
6200  GOTO 6300
6210  END IF
6220  END IF
6230  IF Itt<4 AND Ihm=0 THEN
6240  IF I>4 AND I<9 THEN
6250  T(I)=-99.99
6260  GOTO 6300
6270  END IF
6280  END IF
6290  T(I)=FNTvsv(Emf(I))
6300  NEXT I
6310  IF Itt<4 THEN
6320  FOR I=1 TO 4
6330  IF I=Ldtc1 OR I=Ldtc2 THEN
6340  Twa=Twa
6350  ELSE
6360  Twa=Twa+T(I)
6370  END IF
6380  NEXT I
6390  Twa=Twa/(4-Idtc)
6400  ELSE
6410  IF Ihm=1 THEN 6600
6420  FOR I=1 TO 8
6430  IF I=Ldtc1 OR I=Ldtc2 THEN
6440  Twa=Twa
6450  ELSE
6460  Twa=Twa+T(I)
```

```
6470  END IF
6480  NEXT I
6490  Tw=Twa/(9-Idtc)
6500  IF Hwmntu=1 THEN GOTO 6600
6510  FOR I=9 TO 16
6520  IF I=Aldtc1 OR I=Aldtc2 THEN
6530  Atwa=Atwa
6540  ELSE
6550  Atwa=Atwa+T(I)
6560  END IF
6570  NEXT I
6580  Atw=Atwa/(9-Aidtc)
6590  END IF
6600  Tld=T(17-Nsub)
6610  Tld2=T(19-Nsub)
6620  Tlda=(Tld+Tld2)*.5
6630  Tv=T(19-Nsub)
6640  IF Itt<3 AND Ihm=0 THEN
6650  Tld2=-99.99
6660  Tv=(T(10)+T(11))/2
6670  END IF
6680  Tsump=T(20-Nsub)
6690  IF Ihm=0 THEN 6720
6700  Tinlet=T(13-Nsub)
6710  Tout=T(14-Nsub)
6720  IF Ihm=0 THEN
6730  Amp=ABS(Ir*1.9192)
6740  Volt=ABS(Vr)*25
6750  Q=Volt*Amp
6760  IF Hwmntu=1 THEN GOTO 6800
6770  Auamp=ABS(Air*1.9192)
6780  Auvolt=ABS(Avr)*25
6790  Auq=Auvolt*Auamp
6800  END IF
6810  IF Itt=0 AND Ihm=0 THEN
6820  Kcu=FNKcu(Tw)
6830  ELSE
6840  Kcu=Kcua(Itt)
6850  END IF
6860!
6870! FOURIER CONDUCTION EQUATION WITH CONTACT RESISTANCE NEGLECTED
6880  IF Ihm=0 THEN Tw=Tw-Q*LOG(D2/D1)/(2*PI*Kcu*L)
6890  IF Hwmntu=1 THEN GOTO 6910
6900  IF Ihm=0 THEN Atw=Atw-Auq*LOG(D2/D1)/(2*PI*Kcu*L)
6910  IF Ilqv=0 THEN Tsat=Tlda
6920  IF Ilqv=1 THEN Tsat=Tv
6930  IF Ilqv=2 THEN Tsat=(Tlda+Tv)*.5
6940  IF Ihm=1 THEN
6950  Tavg=Tinlet
6960  Grad=37.9953+.104399*Tavg
6970  Tdrop=ABS(Emf(7))*1.E+6/(10*Grad)
6980  Tavgc=Tinlet-Tdrop*.5
6990  IF ABS(Tavg-Tavgc)>.01 THEN
7000  Tavg=(Tavg+Tavgc)*.5
7010  GOTO 6960
7020  END IF
7030!
7040! COMPUTE WATER PROPERTIES
7050  IF Ihm=1 THEN
7060  Kw=FNKw(Tavg)
```

```
7070  Muwa=FNMuw(Tavg)
7080  Cpw=FNCpw(Tavg)
7090  Prw=FNPrw(Tavg)
7100  Rhow=FNRhow(Tavg)
7110  Twi=Tavg
7120!
7130! Compute MDOT
7140  Mdot=3.3657E-3+Fms*(3.61955E-3-Fms*(8.82005E-6-Fms*(1.23699E-7-Fms*4.31997
E-10)))
7150! Mdot=Mdot*(1.0365-Tinlet*(1.96644E-3-Tinlet*5.252E-6))/1.0037
7160  Kdt=0
7170  Q=Mdot*Cpw*Tdrop
7180  Lmtd=Tdrop/LOG((Tinlet-Tsat)/(Tinlet-Tdrop-Tsat))
7190  Uo=Q/(PI*Do*L*Lmtd)
7200  Rw=Do*LOG(Do/Di)/(2.*Kcu)
7210  Tw=Tsat+Fr*Lmtd
7220  Vw=Mdot/(Rhow*PI*Di^2/4)
7230  Rew=Rhow*Vw*Di/Muwa
7240  Hi=Ci*Kw/Di*Rew^.8*Prw^(1/3.)*(Muwa/FNMuw(Twi))^.14
7250  Twic=Tavg-Q/(PI*Do*L*Hi)
7260  IF ABS(Twi-Twic)>.01 THEN
7270  Twi=(Twi+Twic)*.5
7280  GOTO 7240
7290  END IF
7300  Twi=(Twi+Twic)*.5
7310  Ho=1/(1/Uo-Do/(Di*Hi)-Rw)
7320  END IF
7330  END IF
7340  IF Ihm=1 THEN
7350  Thetab=Q/(Ho*PI*Do*L)
7360  Tw=Tsat+Thetab
7370  ELSE
7380  Thetab=Tw-Tsat
7381  IF Hwmntu=1 THEN GOTO 7400
7390  Athetab=Atw-Tsat
7400  END IF
7410  IF Thetab<0 THEN
7420  BEEP
7430  INPUT "TWALL<TSAT (0=CONTINUE, 1=END)",Iev
7440  IF Iev=0 THEN GOTO 3130
7450  IF Iev=1 THEN 9930
7460  END IF
7470  IF Hwmntu=1 THEN GOTO 7540
7480  IF Athetab<0 THEN
7490  BEEP
7500  INPUT "AUX TWALL<TSAT (0=CONTINUE, 1=END)",Aiev
7510  IF Aiev=0 THEN GOTO 3130
7520  IF Aiev=1 THEN 9930
7530  END IF
7540!
7550! COMPUTE VARIOUS PROPERTIES
7560  Tfilm=(Tw+Tsat)*.5
7570  Rho=FNRho(Tfilm)
7580  Mu=FNMu(Tfilm)
7590  K=FNK(Tfilm)
7600  Cp=FNCp(Tfilm)
7610  Beta=FNBeta(Tfilm)
7620  Hfg=FNHfg(Tsat)
7630  Ni=Mu/Rho
7640  Alpha=K/(Rho*Cp)
```

```
7550  Pr=Ni/Alpha
7560  Psat=FNPsat(Tsat)
7570!
7580! COMPUTE VARIOUS PROPERTIES FOR AUX TUBE
7590  IF Humntu=1 THEN GOTO 7790
7700  Atfilm=(Atw+Tsat)*.5
7710  Arho=FNRho(Atfilm)
7720  Amu=FNMu(Atfilm)
7730  Ak=FNK(Atfilm)
7740  Acp=FNCp(Atfilm)
7750  Abeta=FNBeta(Atfilm)
7760  Ani=Amu/Arho
7770  Aalpha=Ak/(Arho*Acp)
7780  Apr=Ani/Aalpha
7790!
7900! COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
7910! FOR UNENHANCED END(S)
7920  Hbar=190
7930  Fe=(Hbar*P/(Kcu*A))^.5*Lu
7940  Tanh=FNTanh(Fe)
7950  Theta=Thetab*Tanh/Fe
7960  Xx=(9.81*Beta*Thetab*Do^3*Tanh/(Fe*Ni*Alpha))^.166667
7970  Yy=(1+(.559/Pr)^(9/16))^(8/27)
7990  Hbarc=K/Do*(.6+.387*Xx/Yy)^2
7990  IF ABS((Hbar-Hbarc)/Hbarc)>.001 THEN
7900  Hbar=(Hbar+Hbarc)*.5
7910  GOTO 7930
7920  END IF
7930!
7940! COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
7950! FOR UNENHANCED END(S) FOR AUX TUBE
7960  IF Humntu=1 THEN GOTO 8090
7970  Ahbar=190
7980  Fe=(Ahbar*P/(Kcu*A))^.5*Lu
7990  Atanh=FNTanh(Fe)
8000  Atheta=Athetab*Atanh/Fe
8010  Axx=(9.81*Abeta*Athetab*Do^3*Atanh/(Fe*Ani*Aalpha))^.166667
8020  Ayy=(1+(.559/Apr)^(9/16))^(8/27)
8030  Ahbarc=Ak/Do*(.6+.387*Axx/Ayy)^2
8040  IF ABS((Ahbar-Ahbarc)/Ahbarc)>.001 THEN
8050  Ahbar=(Ahbar+Ahbarc)*.5
8060  GOTO 7980
8070  END IF
8080!
8090! COMPUTE HEAT LOSS RATE THROUGH UNENHANCED END(S)
8100  Q1=(Hbar*P*Kcu*A)^.5*Thetab*Tanh
8110  Qc=Q-2*Q1
8120  As=PI*D2*L
8130 !
8140 'COMPUTE HEAT LOSS RATE THROUGH UNENHANCED END(S) OF AUX TUBE
8150  IF Hwmntu=1 THEN GOTO 8190
8160  Aq1=(Ahbar*P*Kcu*A)^.5*Athetab*Atanh
8170  Aqc=Auq-2*Aq1
8180!
8190! COMPUTE ACTUAL HEAT FLUX AND BOILING COEFFICIENT
8200  Qdp=Qc/As
8210  Htube=Qdp/Thetab
8220  Csf=(Cp*Thetab/Hfg)/((Qdp/(Mu*Hfg)*(.011/(9.81*Rho))^.5)^(1/3.)*Pr^1.7)
8230!
8240! COMPUTE ACTUAL HEAT FLUX AND BOILING COEFFICIENT FOR AUX TUBE
```

```
9250  IF Hwmntu=! THEN GOTO 9280
9260  Auqdp=Aqc/As
9270  Ahtube=Auqdp/Athetab
9280  Acsf=(Acp*Athetab/Hfg)/(Auqdp/(Amu*Hfg)*(.014/(9.81*Arho)^.5)^(1/3.)*Apr^1
.7)
9290!
9300! RECORD TIME OF DATA TAKING
9310  IF Im=0 THEN
9320  OUTPUT 709;"TD"
9330  ENTER 709;Told$
9340  END IF
9350!
9360! OUTPUT DATA TO PRINTER
9370  PRINTER IS 701
9380  IF Iov=0 THEN
9390  PRINT
9400 !PRINT USING "10X,""Data Set Number = "",DDD,2X,""Bulk Oil % = "",DD.D,5X,1
4A";J,Bop,Told$
9410  PRINT USING "10X,""Data Set Number = "",DDD,2X,""Bulk Oil % = "",DD.D";J,B
op      .
9420  PRINT "             TIME:",TIME$(TIMEDATE)
9430  IF Ihm=0 THEN
9440  PRINT USING "10X,""TC No:    1       2       3       4       5       6       7
      8"""
9450  PRINT USING "10X,""Temp :"",8(1X,MDD.DD)";T(1),T(2),T(3),T(4),T(5),T(6),T(
7),T(8)
9451  IF Hwmntu=1 THEN GOTO 9480
9460  PRINT USING "10X,""TC No:    9      10      11      12      13      14      15
     16"""
9470  PRINT USING "10X,""Temp :"",8(1X,MDD.DD)";T(9),T(10),T(11),T(12),T(13),T(1
4),T(15),T(16)
9480  PRINT USING "10X,""  Twa    ATwa   Tl:qd   Tl:qd2  Tvapr  Psat   Tsump"""
9490  PRINT USING "10X,3(MDD.DD,1X),1X,MDD.DD,1X,2(1X,MDD.DD),2X,MDD.D";Tw,Atw,T
ld,Tld2,Tv,Psat,Tsump
9500  PRINT USING "10X,"" Thetab  Htube      Qdp          Athetab Ahtube     AuQd
p"""
9510  PRINT USING "10X,MDD.3D,1X,MZ.3DE,1X,MZ.3DE,1X,MDD.3D,1X,MZ.3DE,1X,MZ.3DE"
;Thetab,Htube,Qdp,Athetab,Ahtube,Auqdp
9520  ELSE
9530  PRINT USING "10X,"" Fms     Vw    Tsat   Tinl Tdrop Thetab      q          Uo
       Ho"""
9540  PRINT USING "10X,4(2D.DD,1X),Z.3D,1X,DD.DD,1X,3(MZ.3DE,1X)";Fms,Vw,Tsat,Ti
nlet,Tdrop,Thetab,Qdp,Uo,Ho
9550  END IF
9560  END IF
9570  IF Iov=1 THEN
9580  IF J=1 THEN
9590  PRINT
9600  IF Ihm=0 THEN
9610  PRINT USING "10X,"" RUN No  Oil%  Tsat    Htube      Qdp        Thetab"""
9620  ELSE
9630  PRINT USING "10X,""  FMS    OIL%  TSAT    HTUBE      QDP        THETAB"""
9640  END IF
9650  END IF
9660  IF Ihm=0 THEN
9670  PRINT USING "12X,3D,4X,DD,2X,MDD.DD,3(1X,MZ.3DE)";J,Bop,Tsat,Htube,Qdp,The
tab
9680  ELSE
9690  PRINT USING "12X,3D,4X,DD,2X,MDD.DD,3(1X,MZ.3DE)";Fms,Bop,Tsat,Htube,Qdp,T
hetab
```

```
8700  END IF
8710  END IF
8720  IF Im=0 THEN
8730  BEEP
8740  INPUT "OK TO STORE THIS DATA SET (1=Y,0=N)?",Ok
8750  END IF
8760  IF Ok=1 OR Im=1 THEN J=J+1
8770  IF Ok=1 AND Im=0 THEN
8780  IF Ihm=0 THEN OUTPUT @File1;Bop,Told$,Emf(*),Vr,Ir,Avr,Air
8790  IF Ihm=1 THEN OUTPUT @File1;Bop,Told$,Emf(*),Fms
8800  END IF
8810  IF Iuf=1 THEN OUTPUT @Ufile;Vw,Uo
8820  IF Ire=1 THEN OUTPUT @Refile;Fms,Rew
8830  IF (Im=1 OR Ok=1) AND Iplot=1 THEN OUTPUT @Plot;Qdp,Thetab
8840  IF Im=0 THEN
8850  BEEP
8860  INPUT "WILL THERE BE ANOTHER RUN (1=Y,0=N)?",Go_on
8870  Nrun=J
8880  IF Go_on=0 THEN 8930
8890  IF Go_on<>0 THEN Repeat
8900  ELSE
8910  IF J<Nrun+1 THEN Repeat
8920  END IF
8930  IF Im=0 THEN
8940  BEEP
8950  PRINT USING "10X,""NOTE: "",ZZ,"" data runs were stored in file "",10A";J-
1,D2_file$
8960  ASSIGN @File1 TO *
8970  OUTPUT @File2;Nrun-1
8980  ASSIGN @File1 TO D1_file$
8990  ENTER @File1;Date$,Ldtc1,Ldtc2,Itt
8991  IF Humntu=1 THEN GOTO 9000
8993  ENTER @File1;Aldtc1,Aldtc2
9000  OUTPUT @File2;Date$,Ldtc1,Ldtc2,Itt
9001  IF Humntu=1 THEN GOTO 9010
9003  OUTPUT @File2;Aldtc1,Aldtc2
9010  FOR I=1 TO Nrun-1
9020  IF Ihm=0 THEN
9030  ENTER @File1;Bop,Told$,Emf(*),Vr,Ir
9040  IF Humntu=1 THEN GOTO 9060
9050  ENTER @File1;Avr,Air
9060  OUTPUT @File2;Bop,Told$,Emf(*),Vr,Ir
9070  IF Humntu=1 THEN GOTO 9090
9080  OUTPUT @File2;Avr,Air
9090  ELSE
9100  ENTER @File1;Bop,Told$,Emf(*),Fms
9110  OUTPUT @File2;Bop,Told$,Emf(*),Fms
9120  END IF
9130. NEXT I
9140  ASSIGN @File1 TO *
9150  PURGE "DUMMY"
9160  END IF
9170  BEEP
9180  PRINT
9190  IF Iplot=1 THEN PRINT USING "10X,""NOTE: "",ZZ,"" X-Y pairs were stored in
 plot data file "",10A";J-1,P_file$
9200  ASSIGN @File2 TO *
9210  ASSIGN @Plot TO *
9220  IF Iuf=1 THEN ASSIGN @Ufile TO *
9230  IF Ire=1 THEN ASSIGN @Refile TO *
```

```
9240  CALL Stats
9250  BEEP
9260  INPUT "LIKE TO PLOT DATA (1=Y,0=N)?",Ok
9270  IF Ok=1 THEN CALL Plot
9280  SUBEND
9290!
9300! CURVE FITS OF PROPERTY FUNCTIONS
9310  DEF FNKcu(T)
9320! OFHC COPPER 250 TO 300 K
9330  Tk=T+273.15      !C TO K
9340  K=434-.112*Tk
9350  RETURN K
9360  FNEND
9370  DEF FNMu(T)
9380! 170 TO 350 K CURVE FIT OF VISCOUSITY
9390  Tk=T+273.15      !C TO K
9400  Mu=EXP(-4.4636+(1011.47/Tk))*1.0E-3
9410  RETURN Mu
9420  FNEND
9430  DEF FNCp(T)
9440! 180 TO 400 K CURVE FIT OF Cp
9450  Tk=T+273.15      !C TO K
9460  Cp=.40198+1.65007E-3*Tk+1.51494E-6*Tk^2-6.67853E-10*Tk^3
9470  Cp=Cp*1000
9480  RETURN Cp
9490  FNEND
9500  DEF FNRho(T)
9510  Tk=T+273.15      !C TO K
9520  X=1-(1.8*Tk/753.95)  !K TO R
9530  Ro=36.32+61.146414*X^(1/3)+16.418015*X+17.476838*X^.5+1.119829*X^2
9540  Ro=Ro/.062428
9550  RETURN Ro
9560  FNEND
9570  DEF FNPr(T)
9580  Pr=FNCp(T)*FNMu(T)/FNK(T)
9590  RETURN Pr
9600  FNEND
9610  DEF FNK(T)
9620! T<360 K WITH T IN C
9630  K=.071-.000251*T
9640  RETURN K
9650  FNEND
9660  DEF FNTanh(X)
9670  P=EXP(X)
9680  Q=1/P
9690  Tanh=(P-Q)/(P+Q)
9700  RETURN Tanh
9710  FNEND
9720  DEF FNTvsv(V)
9730  COM /Cc/ C(7),Ical
9740  T=C(0)
9750  FOR I=1 TO 7
9760  T=T+C(I)*V^I
9770  NEXT I
9780  IF Ical=1 THEN
9790  T=T-6.7422934E-2+T*(9.0277043E-3-T*(-9.3259917E-5))
9800  ELSE
9810  T=T+9.6259987E-2+T*(3.751395E-3-T*5.0638258E-5)
9820  END IF
9830  RETURN T
```

```
9840  FNEND
9850  DEF FNBeta(T)
9860  Rop=FNRho(T+.1)
9870  Rom=FNRho(T-.1)
9880  Beta=-2/(Rop+Rom)*(Rop-Rom)/.2
9890  RETURN Beta
9900  FNEND
9910  DEF FNHfg(T)
9920  Hfg=1.3741344E+5-T*(3.3094361E+2+T*1.2165143)
9930  RETURN Hfg
9940  FNEND
9950  DEF FNPsat(Tc)
9960! 0 TO 80 deg F CURVE FIT OF Psat
9970  Tf=1.8*Tc+32
9980  Pa=5.945525+Tf*(.15352082+Tf*(1.4840963E-3+Tf*9.6150671E-6))
9990  Pg=Pa-14.7
10000 IF Pg>0 THEN        ! +=PSIG,-=in Hg
10010 Psat=Pg
10020 ELSE
10030 Psat=Pg*29.92/14.7
10040 END IF
10050 RETURN Psat
10060 FNEND
10070 DEF FNHsmooth(X,Bop,Isat)
10080 DIM A(5),B(5),C(5),D(5)
10090 DATA .20525,.25322,.319048,.55322,.79909,1.00258
10100 DATA .74515,.72992,.73189,.71225,.68472,.64197
10110 DATA .41092,.17726,.25142,.54906,.81916,1.0945
10120 DATA .74403,.72913,.72565,.696691,.665867,.61899
10130 READ A(*),B(*),C(*),D(*)
10140 IF Bop<6 THEN I=Bop
10150 IF Bop=6 THEN I=4
10160 IF Bop=10 THEN I=5
10170 IF Isat=1 THEN
10180 Hs=EXP(A(I)+B(I)*LOG(X))
10190 ELSE
10200 Hs=EXP(C(I)+D(I)*LOG(X))
10210 END IF
10220 RETURN Hs
10230 FNEND
10240 DEF FNPoly(X)
10250 COM /Cply/ A(10,10),C(10),B(5),Nop,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
10260 X1=X
10270 Poly=B(0)
10280 FOR I=1 TO Nop
10290 IF Ilog=1 THEN X1=LOG(X)
10300 Poly=Poly+B(I)*X1^I
10310 NEXT I
10320 IF Ilog=1 THEN Poly=EXP(Poly)
10330 RETURN Poly
10340 FNEND
10350 SUB Poly
10360 DIM R(10),S(10),Sy(10),Sx(10),Xx(100),Yy(100)
10370 COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
10380 COM /Xxyy/ Xp(25),Yp(25)
10390 FOR I=0 TO 4
10400 B(I)=0
10410 NEXT I
10420 BEEP
10430 INPUT "SELECT (0=FILE,1=KEYBOARD,2=PROGRAM)",Im
```

```
10440 Im=Im+1
10450 BEEP
10460 INPUT "ENTER NUMBER OF X-Y PAIRS",Np
10470 IF Im=1 THEN
10480 BEEP
10490 INPUT "ENTER DATA FILE NAME",D_file$
10500 BEEP
10510 INPUT "LIKE TO EXCLUDE DATA PAIRS (1=Y,0=N)?",Ied
10520 IF Ied=1 THEN
10530 BEEP
10540 INPUT "ENTER NUMBER OF PAIRS TO BE EXCLUDED",Ipex
10550 END IF
10560 ASSIGN @File TO D_file$
10570 ELSE
10580 BEEP
10590 INPUT "WANT TO CREATE A DATA FILE (1=Y,0=N)?",Yes
10600 IF Yes=1 THEN
10610 BEEP
10620 INPUT "GIVE A NAME FOR DATA FILE",D_file$
10630 CREATE BDAT D_file$,5
10640 ASSIGN @File TO D_file$
10650 END IF
10660 END IF
10670 BEEP
10680 INPUT "ENTER THE ORDER OF POLYNOMIAL",N
10690 FOR I=0 TO N*2
10700 Sy(I)=0
10710 Sx(I)=0
10720 NEXT I
10730 IF Ied=1 AND Im=1 THEN
10740 FOR I=1 TO Ipex
10750 ENTER @File;X,Y
10760 NEXT I
10770 END IF
10780 FOR I=1 TO Np
10790 IF Im=1 THEN
10800 IF Opo=2 THEN ENTER @File;X,Y
10810 IF Opo<2 THEN ENTER @File;Y,X
10820 IF Opo=1 THEN Y=Y/X
10830 IF Ilog=1 THEN
10840 IF Opo=2 THEN Xt=X/Y
10850 X=LOG(X)
10860 IF Opo=2 THEN Y=LOG(Xt)
10870 IF Opo<2 THEN Y=LOG(Y)
10880 END IF
10890 END IF
10900 IF Im=2 THEN
10910 BEEP
10920 INPUT "ENTER NEXT X-Y PAIR",X,Y
10930 IF Yes=1 THEN OUTPUT @File;X,Y
10940 END IF
10950 IF Im<3 THEN
10960 Xx(I)=X
10970 Yy(I)=Y
10980 ELSE
10990 X=Xp(I-1)
11000 Y=Yp(I-1)
11010 END IF
11020 R(0)=Y
11030 Sy(0)=Sy(0)+Y
```

```
11040 S(1)=X
11050 Sx(1)=Sx(1)+X
11060 FOR J=1 TO N
11070 R(J)=R(J-1)*X
11080 Sy(J)=Sy(J)+R(J)
11090 NEXT J
11100 FOR J=2 TO N*2
11110 S(J)=S(J-1)*X
11120 Sx(J)=Sx(J)+S(J)
11130 NEXT J
11140 NEXT I
11150 IF Yes=1 AND Im=2 THEN
11160 BEEP
11170 PRINT USING "12X,DD,"" X-Y pairs were stored in file "",10A";Np,D_file$
11180 END IF
11190 Sx(0)=Np
11200 FOR I=0 TO N
11210 C(I)=Sy(I)
11220 FOR J=0 TO N
11230 A(I,J)=Sx(I+J)
11240 NEXT J
11250 NEXT I
11260 FOR I=0 TO N-1
11270 CALL Divide(I)
11280 CALL Subtract(I+1)
11290 NEXT I
11300 B(N)=C(N)/A(N,N)
11310 FOR I=0 TO N-1
11320 B(N-1-I)=C(N-1-I)
11330 FOR J=0 TO I
11340 B(N-1-I)=B(N-1-I)-A(N-1-I,N-J)*B(N-J)
11350 NEXT J
11360 B(N-1-I)=B(N-1-I)/A(N-1-I,N-1-I)
11370 NEXT I
11380!PRINTER IS 701
11390!PRINT B(*)
11400!PRINTER IS 705
11410 IF Iprnt=0 THEN
11420 PRINT USING "12X,""EXPONENT    COEFFICIENT"""
11430 FOR I=0 TO N
11440 PRINT USING "15X,DD,5X,MD.7DE";I,B(I)
11450 NEXT I
11460 PRINT " "
11470 PRINT USING "12X,""DATA POINT       X              Y       Y(CALCULATED) DISCR
EPANCY"""
11480 FOR I=1 TO Np
11490 Yc=B(0)
11500 FOR J=1 TO N
11510 Yc=Yc+B(J)*Xx(I)^J
11520 NEXT J
11530 D=Yy(I)-Yc
11540 PRINT USING "15X,3D,4X,4(MD.5DE,1X)";I,Xx(I),Yy(I),Yc,D
11550 NEXT I
11560 END IF
11570 ASSIGN @File TO *
11580 SUBEND
11590 SUB Divide(M)
11600 COM /Poly/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
11610 FOR I=M TO N
11620 Ao=A(I,M)
```

```
11630 FOR J=M TO N
11640 A(I,J)=A(I,J)/Ac
11650 NEXT J
11660 C(I)=C(I)/Ac
11670 NEXT I
11680 SUBEND
11690 SUB Subtract(K)
11700 COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
11710 FOR I=K TO N
11720 FOR J=K-1 TO N
11730 A(I,J)=A(K-1,J)-A(I,J)
11740 NEXT J
11750 C(I)=C(K-1)-C(I)
11760 NEXT I
11770 SUBEND
11780 SUB Plin
11790 COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
11800 COM /Xxyy/ Xx(25),Yy(25)
11810 PRINTER IS 705
11820 BEEP
11830 INPUT "WANT TO PLOT Uo vs Uw? (1=Y,0=N)",Iuo
11840 IF Iuo=0 THEN
11850 BEEP
11860 INPUT "SELECT (0=h/h0% same tube,1=h(HF)/h(sm)",Irt
11870 BEEP
11880 INPUT "SELECT h/h RATIO (1=FILE,0=COMPUTED)",Ihrat
11890 IF Ihrat=0 THEN
11900 BEEP
11910 INPUT "WHICH Tsat (1=6.7,0=-2.2)",Isat
11920 END IF
11930 Xmin=0
11940 Xmax=10
11950 Xstep=2
11960 IF Irt=0 THEN
11970 Ymin=0
11980 Ymax=1.4
11990 Ystep=.2
12000 ELSE
12010 Ymin=0
12020 Ymax=15
12030 Ystep=5
12040 END IF
12050 ELSE
12060 Opo=2
12070 Ymin=0
12080 Ymax=12
12090 Ystep=3
12100 Xmin=0
12110 Xmax=4
12120 Xstep=1
12130 END IF
12140 IF Ihrat=1 THEN
12150 Ymin=0
12160 Ymax=18
12170 Ystep=3
12180 Xmin=0
12190 Xmax=9
12200 Xstep=2
12210 END IF
12220 BEEP
```

```
12230 PRINT "IN;SP1;IP 2200,2200,3300,5300;"
12240 PRINT "SC 0,100,0,100:TL 2,0:"
12250 Sfx=100/(Xmax-Xmin)
12260 Sfy=100/(Ymax-Ymin)
12270 PRINT "PU 0,0 PD"
12280 FOR Xa=Xmin TO Xmax STEP Xstep
12290 X=(Xa-Xmin)*Sfx
12300 PRINT "PA";X,",0; XT;"
12310 NEXT Xa
12320 PRINT "PA 100,0;PU;"
12330 PRINT "PU PA 0,0 PD"
12340 FOR Ya=Ymin TO Ymax STEP Ystep
12350 Y=(Ya-Ymin)*Sfy
12360 PRINT "PA 0,";Y,"YT"
12370 NEXT Ya
12380 PRINT "PA 0,100 TL 0 2"
12390 FOR Xa=Xmin TO Xmax STEP Xstep
12400 X=(Xa-Xmin)*Sfx
12410 PRINT "PA";X,",100; XT"
12420 NEXT Xa
12430 PRINT "PA 100,100 PU PA 100,0 PD"
12440 FOR Ya=Ymin TO Ymax STEP Ystep
12450 Y=(Ya-Ymin)*Sfy
12460 PRINT "PD PA 100,",Y,"YT"
12470 NEXT Ya
12480 PRINT "PA 100,100 PU"
12490 PRINT "PA 0,-2 SR 1.5,2"
12500 FOR Xa=Xmin TO Xmax STEP Xstep
12510 X=(Xa-Xmin)*Sfx
12520 PRINT "PA";X,",0;"
12530 IF Iuo=0 THEN PRINT "CP -2,-1;LB";Xa;""
12540 IF Iuo=1 THEN PRINT "CP -1.5,-1;LB";Xa;""
12550 NEXT Xa
12560 PRINT "PU PA 0,0"
12570 FOR Ya=Ymin TO Ymax STEP Ystep
12580 IF ABS(Ya)<1.E-5 THEN Ya=0
12590 Y=(Ya-Ymin)*Sfy
12600 PRINT "PA 0,";Y,""
12610 IF Iuo=0 THEN PRINT "CP -4,-.25;LB";Ya;""
12620 IF Iuo=1 THEN PRINT "CP -3,-.25;LB";Ya;""
12630 NEXT Ya
12640 Xlabel$="Oil Percent"
12650 IF Iuo=0 THEN
12660 IF Irt=0 THEN
12670 Ylabel$="h/h0%"
12680 ELSE
12690 Ylabel$="h/hsmooth"
12700 END IF
12710 PRINT "SR 1.5,2;PU PA 50,-10 CP";-LEN(Xlabel$)/2;"0;LB";Xlabel$;""
12720 PRINT "PA -11,50 CP 0,";-LEN(Ylabel$)/2*5/6;"DI 0,1;LB";Ylabel$;""
12730 PRINT "CP 0,0"
12740 ELSE
12750 PRINT "SP0;SP2"
12760 PRINT "SR 1.2,2.4;PU PA -8,35;DI 0,1;LBU;PR 1,0.5;LBo;PR -1,0.5;LB (kW/m
"

12770 PRINT "PR -1,0.5;SR 1,1.5;LB2;SR 1.5,2;PR .5,.5;LB.;PR .5,0;LBK)"
12780 PRINT "PA 42,-10;DI 1,0;LBU;PR .1,-1;LBw;PR 1,.5;LB(m/s)"
12790 PRINT "SP0;SP1"
12800 END IF
12810 Ipn=0
```

```
12820 BEEP
12830 INPUT "WANT TO PLOT DATA FROM A FILE (1=Y,0=N)?",Olp
12840 Icn=0
12850 IF Olp=1 THEN
12860 BEEP
12870 INPUT "ENTER THE NAME OF THE DATA FILE",D_file$
12880! IF Iuo=0 THEN
12890 BEEP
12900 INPUT "SELECT (0=LINEAR, 1=LOG(X,Y)",Ilog
12910! END IF
12920 ASSIGN @File TO D_file$
12930 BEEP
12940 INPUT "ENTER THE BEGINNING RUN NUMBER",Md
12950 BEEP
12960 INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED",Npairs
12970 IF Iuo=0 AND Ihrat=0 THEN
12980 BEEP
12990 INPUT "ENTER DESIRED HEAT FLUX",Q
13000 END IF
13010 BEEP
13020 PRINTER IS 1
13030 PRINT USING "4X,""Select a symbol:"""
13040 PRINT USING "4X,""1  Star   2  Plus sign"""
13050 PRINT USING "4X,""3  Circle 4  Square"""
13060 PRINT USING "4X,""5  Rombus"""
13070 PRINT USING "4X,""6  Right-side-up triangle"""
13080 PRINT USING "4X,""7  Up-side-down triangle"""
13090 INPUT Sym
13100 PRINTER IS 705
13110 PRINT "PU DI"
13120 IF Sym=1 THEN PRINT "SM*"
13130 IF Sym=2 THEN PRINT "SM+"
13140 IF Sym=3 THEN PRINT "SMo"
13150 Nn=4
13160 IF Ilog=1 THEN Nn=1
13170 IF Md>1 THEN
13180 FOR I=1 TO (Md-1)
13190 ENTER @File;Xa,Ya
13200 NEXT I
13210 END IF
13220 IF Ihrat=0 THEN
13230 Q1=Q
13240 IF Ilog=1 THEN Q=LOG(Q)
13250 END IF
13260 FOR I=1 TO Npairs
13270 IF Iuo=0 AND Ihrat=0 THEN
13280 ENTER @File;Xa,B(*)
13290 Ya=B(0)
13300 FOR K=1 TO Nn
13310 Ya=Ya+B(K)*Q^K
13320 NEXT K
13330 END IF
13340 IF Iuo=1 OR Ihrat=1 THEN
13350 ENTER @File;Xa,Ya
13360 IF Iuo=1 THEN Ya=Ya/1000
13370 END IF
13380 IF Iuo=0 AND Ihrat=0 THEN
13390 IF Ilog=1 THEN Ya=EXP(Ya)
13400 IF Ilog=0 THEN Ya=Q1/Ya
13410 IF Irt=0 THEN
```

```
13420 IF Xa=0 THEN
13430 Yo=Ya
13440 Ya=1
13450 ELSE
13460 Ya=Ya/Yo
13470 END IF
13480 ELSE
13490 Hsm=FNHsmooth(Q,Xa,Isat)
13500 Ya=Ya/Hsm
13510 END IF
13520 END IF
13530 Xx(I-1)=Xa
13540 Yy(I-1)=Ya
13550 X=(Xa-Xmin)*Sfx
13560 Y=(Ya-Ymin)*Sfy
13570 IF Sym>3 THEN PRINT "SM"
13580 IF Sym<4 THEN PRINT "SR 1.4,2.4"
13590 PRINT "PA",X,Y,""
13600 IF Sym>3 THEN PRINT "SR 1.2,1.6"
13610 IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,8,4,0,;"
13620 IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,6,3,6,3,-6;"
13630 IF Sym=6 THEN PRINT "UC0,5.3,99,3,-9,-6,0,3,9;"
13640 IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,9,6,0,-3,-9;"
13650 NEXT I
13660 BEEP
13670 ASSIGN @File TO *
13680 END IF
13690 PRINT "PU SM"
13700 BEEP
13710 INPUT "WANT TO PLOT A POLYNOMIAL (1=Y,0=N)?",Okp
13720 IF Okp=1 THEN
13730 BEEP
13740 PRINTER IS 1
13750 PRINT USING "4X,""Select line type:"""
13760 PRINT USING "6X,""0      Solid line"""
13770 PRINT USING "6X,""1      Dashed"""
13780 PRINT USING "6X,""2,,,6 Longer line - dash"""
13790 INPUT Ipn
13800 PRINTER IS 705
13810 BEEP
13820 INPUT "SELECT (0=LINEAR,1=LOG(X,Y))",Ilog
13830 Iprnt=1
13840 CALL Poly
13850 IF Iuo=1 THEN
13860 BEEP
13870 INPUT "DESIRE TO SET X Lower and Upper Limit (1=Y,0=N)?",Ixlim
13880 IF Ixlim=0 THEN
13890 Xll=0
13900 Xul=7
13910 END IF
13920 IF Ixlim=1 THEN
13930 BEEP
13940 INPUT "ENTER X Lower Limit",Xll
13950 BEEP
13960 INPUT "ENTER X Upper Limit",Xul
13970 END IF
13980 END IF
13990 FOR Xa=Xll TO Xul STEP Xstep/25
14000 Ipn=Ipn+1
14010 Ya=FNPoly(Xa)
```

```
14020 IF Iuc=1 THEN Ya=Ya 1000
14030 Y=(Ya-Ymin)*Sfy
14040 X=(Xa-Xmin)*Sfx
14050 IF Y<0 THEN Y=0
14060 IF Y>100 THEN GOTO 14160
14070 Pu=0
14080 IF Ipn=1 THEN Idf=Icn MOD 2
14090 IF Ipn=2 THEN Idf=Icn MOD 4
14100 IF Ipn=3 THEN Idf=Icn MOD 8
14110 IF Ipn=4 THEN Idf=Icn MOD 16
14120 IF Ipn=5 THEN Idf=Icn MOD 32
14130 IF Idf=1 THEN Pu=1
14140 IF Pu=0 THEN PRINT "PA",X,Y,"PD"
14150 IF Pu=1 THEN PRINT "PA",X,Y,"PU"
14160 NEXT Xa
14170 PRINT "PU"
14180 GOTO 12920
14190 END IF
14200 BEEP
14210 INPUT "WANT TO QUIT (1=Y,0=N)?",Iquit
14220 IF Iquit=1 THEN 14240
14230 GOTO 12820
14240 PRINT "PU SP0"
14250 SUBEND
14260 SUB Stats
14270 PRINTER IS 701
14280 J=0
14290 K=0
14300 BEEP
14310 IF Iplot=1 THEN ASSIGN @File TO P_file$
14320 BEEP
14330 INPUT "LAST RUN No?(0=QUIT)",Nn
14340 IF Nn=0 THEN 14700
14350 Nn=Nn-J
14360 Sx=0
14370 Sy=0
14380 Sz=0
14390 Sxs=0
14400 Sys=0
14410 Szs=0
14420 FOR I=1 TO Nn
14430 J=J+1
14440 ENTER @File;Q,T
14450 H=Q/T
14460 Sx=Sx+Q
14470 Sxs=Sxs+Q^2
14480 Sy=Sy+T
14490 Sys=Sys+T^2
14500 Sz=Sz+H
14510 Szs=Szs+H^2
14520 NEXT I
14530 Qave=Sx/Nn
14540 Tave=Sy/Nn
14550 Have=Sz/Nn
14560 Sdevq=SQR(ABS((Nn*Sxs-Sx^2)/(Nn*(Nn-1))))
14570 Sdevt=SQR(ABS((Nn*Sys-Sy^2)/(Nn*(Nn-1))))
14580 Sdevh=SQR(ABS((Nn*Szs-Sz^2)/(Nn*(Nn-1))))
14590 Sh=100*Sdevh/Have
14600 Sq=100*Sdevq/Qave
14610 St=100*Sdevt/Tave
```

```
14520 IF K=1 THEN 14580
14530 PRINT
14540 PRINT USING "11X,""DATA FILE:"",14A";Files
14550 PRINT
14560 PRINT USING "11X,""RUN Htube      SdevH    Qdp          SdevQ    Thetab SdevT"""
14570 K=1
14580 PRINT USING "11X,DD,2(2X,D.3DE,1X,3D.2D),2X,DD.3D,1X,3D.2D";J,Have,Sh,Qave
,Sq,Tave,St
14590 GOTO 14320
14700 ASSIGN @File1 TO *
14710 PRINTER IS 1
14720 SUBEND
14730 SUB Coef
14740 COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
14750 BEEP
14760 INPUT "GIVE A NAME FOR CROSS-PLOT FILE",Cpf$
14770 CREATE BDAT Cpf$,2
14780 ASSIGN @File TO Cpf$
14790 BEEP
14800 INPUT "SELECT (0=LINEAR,1=LOG(X,Y))",Ilog
14810 BEEP
14820 INPUT "ENTER OIL PERCENT (-1=STOP)",Bop
14830 IF Bop<0 THEN 14870
14840 CALL Poly
14850 OUTPUT @File;Bop,B(*)
14860 GOTO 14810
14870 ASSIGN @File TO *
14880 SUBEND
14890 SUB Wilson(Cf,Ci)
14900 COM /Wil/ D2,Di,Do,L,Lu,Kcu
14910 DIM Emf(12)
14920! WLISON PLOT SUBROUTINE DETERMINE CF AND CI
14930 BEEP
14940 INPUT "ENTER DATA FILE NAME",Files
14950 BEEP
14960 PRINTER IS 1
14970 PRINT USING "4X,""Select option:"""
14980 PRINT USING "4X,""  0 Vary Cf and  Ci"""
14990 PRINT USING "4X,""  1 Fix  Cf Vary Ci"""
15000 PRINT USING "4X,""  2 Vary Cf Fix  Ci"""
15010 INPUT "ENTER OPTION",Icfix
15020 PRINTER IS 701
15030 IF Icfix=0 THEN 15070
15040 IF Icfix>0 THEN BEEP
15050 IF Icfix=1 THEN INPUT "ENTER Cf",Csf
15060 IF Icfix=2 THEN INPUT "ENTER CI",Ci
15070 PRINTER IS 1
15080 INPUT "Want To Vary Coeff?(1=Y,0=N)",Iccoef
15090 IF Iccoef=1 THEN INPUT "ENTER COEFF",R
15100 PRINTER IS 701
15110 IF Icfix=0 OR Icfix=2 THEN Cfa=.004
15120 IF Icfix=1 THEN Cfa=Csf
15130 Cia=Ci
15140 Kn=.8
15150 Fr=.3
15160 Jj=0
15170 Rr=3.
15180 IF Iccoef=1 THEN Rr=R
15190 PRINTER IS 1
```

```
15200 PRINT Do,Di,Kcu
15210 ASSIGN @File TO File$
15220 ENTER @File;Nrun,Date$,Ldtc1,Ldtc2,Itt
15230 Rw=Do*LOG(Do/Di)/(2*Kcu)
15240 Sx=0
15250 Sy=0
15260 Sxy=0
15270 Sx2=0
15280 Sy2=0
15290 FOR I=1 TO Nrun
15300 ENTER @File;Bop,Told$,Emf(*),Fms
15310! CONVERT EMF'S TO TEMPERATURE
15320 FOR J=1 TO 5
15330 T(J)=FNTvsv(Emf(J))
15340 NEXT J
15350 Tsat=(T(1)+T(2))*.5
15360 Tavg=T(5)
15370 Grad=37.9853+.104389*Tavg
15380 Tdrop=Emf(7)*1.E+6/(10.*Grad)
15390 Tavgc=T(5)-Tdrop*.5
15400 IF ABS(Tavg-Tavgc)>.01 THEN
15410 Tavg=(Tavg+Tavgc)*.5
15420 GOTO 15370
15430 END IF
15440!
15450! Compute properties of water
15460 Kw=FNKw(Tavg)
15470 Muwa=FNMuw(Tavg)
15480 Cpw=FNCpw(Tavg)
15490 Prw=FNPrw(Tavg)
15500 Rhow=FNRhow(Tavg)
15510!
15520! Compute properties of Freon-114
15530 Lmtd=Tdrop/LOG((T(5)-Tsat)/(T(5)-Tdrop-Tsat))
15540 IF Jj=0 THEN
15550 Tw=Tsat+Fr*Lmtd
15560 Thetab=Tw-Tsat
15570 Jj=1
15580 END IF
15590 Tf=(Tw+Tsat)*.5
15600 Rho=FNRho(Tf)
15610 Mu=FNMu(Tf)
15620 K=FNK(Tf)
15630 Cp=FNCp(Tf)
15640 Beta=FNBeta(Tf)
15650 Hfg=FNHfg(Tsat)
15660 Ni=Mu/Rho
15670 Alpha=K/(Rho*Cp)
15680 Pr=Ni/Alpha
15690!
15700! Analysis
15710! COMPUTE MDOT
15720 A=PI*(Do^2-Di^2)/4
15730 P=PI*Do
15740 Mdot=3.9557E-3+Fms*(3.61955E-3-Fms*(9.82005E-5-Fms*(1.23989E-7-Fms*4.31897
E-10)))
15750 Q=Mdot*Cpw*Tdrop
15760! COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
15770! FOR UNENHANCED END(S)
15790 Hbar=190
```

```
15790 Fe=(Hbar*P/(Kcu*A))^.5*Lu
15800 Tanh=FNTanh(Fe)
15810 Theta=Thetab*Tanh/Fe
15820 Xx=(9.81*Beta*Thetab*Do^3*Tanh/(Fe*Nu*Alpha))^.166667
15830 Yy=(1+(.559/Pr)^(9/16))^(8/27)
15840 Hbarc=K/Do*(.6+.387*Xx/Yy)^2
15850 IF ABS((Hbar-Hbarc)/Hbar)>.001 THEN
15860 Hbar=(Hbar+Hbarc)*.5
15870 GOTO 15790
15880 END IF
15890!
15900! COMPUTE HEAT LOSS RATE THROUGH UNENHANCED ENDS
15910 Q1=(Hbar*P*Kcu*A)^.5*Thetab*Tanh
15920 Qc=Q-2*Q1
15930 As=PI*D2*L
15940! COMPUTE ACTUAL HEAT FLUX
15950 Qdp=Qc/As
15960 IF Icfix=0 OR Icfix>1 THEN Csf=1/Cf^(1./Rr)
15970 Thetab=Csf/Cp*Hfg*(Qdp/(Mu*Hfg)*(.014/(9.81*Rho))^.5)^(1/Rr)*Pr^1.7
15980 Ho=Qdp/Thetab
15990 Omega=Ho/Cf
16000 Uo=Q/(PI*Do*L*Lmtd)
16010 Vw=Mdot/(Rhow*PI*Di^2/4)
16020 Rew=Rhow*Vw*Di/Muwa
16030 Twi=Tw+Q*Rw/(PI*Do*L)
16040 Gama=Kw/Di*Rew^.8*Prw^(1/3.)*(Muwa/FNMuw(Twi))^.14
16050! PRINTER IS 1
16060 Yw=(1./Uo-Rw)*Omega
16070 Xw=Omega*Do/(Gama*Di)
16080 Sx=Sx+Xw
16090 Sy=Sy+Yw
16100 Sxy=Sxy+Yw*Xw
16110 Sx2=Sx2+Xw*Xw
16120 Sy2=Sy2+Yw*Yw
16130 NEXT I
16140 ASSIGN @File TO *
16150 M=(Sx*Sy-Nrun*Sxy)/(Sx*Sx-Nrun*Sx2)
16160 C=(Sy-Sx*M)/Nrun
16170 IF Icfix=0 OR Icfix=3 OR Icfix=4 THEN
16180 Cic=1/M
16190 Cfc=1/C
16200 END IF
16210 IF Icfix=1 THEN
16220 Cic=1/M
16230 Cfc=Cf
16240 END IF
16250 IF Icfix=2 THEN
16260 Cic=Ci
16270 Cfc=1/C
16280 END IF
16290 IF ABS((Ci-Cic)/Cic)>.001 OR ABS((Cf-Cfc)/Cfc)>.001 THEN
16300 Ci=(Ci+Cic)*.5
16310 Cf=(Cf+Cfc)*.5
16320 PRINTER IS 1
16330 PRINT USING "2X,"" Csf = "",MZ.3DE,2X,"" Ci = "",MZ.3DE";Csf,Ci
16340 PRINTER IS 701
16350 GOTO 15210
16360 END IF
16370 PRINT
16380 PRINTER IS 701
```

```
16390 PRINT USING "23X,""  Cf              Ci"""
16400 PRINT USING "9X,""ASSUMED       "",MZ.3DE,3X,MZ.3DE";Cfa,Cia
16410 PRINT USING "9X,""CALCULATED    "",MZ.3DE,3X,MZ.3DE";Csf,Ci
16420 PRINT
16430 Sum2=Sy2-2*M*Sxy-2*C*Sy+M^2*Sx2+2*M*C*Sx+Nrun*C^2
16440 PRINT USING "10X,""Sum of Squares = "",Z.3DE";Sum2
16450 PRINT USING "10X,""Coefficient = "",D.DDD";Rr
16460 SUBEND
16470 DEF FNMuw(T)
16480 A=247.8/(T+133.15)
16490 Mu=2.4E-5*10^A
16500 RETURN Mu
16510 FNEND
16520 DEF FNCpw(T)
16530 Cpw=4.21120858-T*(2.26826E-3-T*(4.42361E-5+2.71428E-7*T))
16540 RETURN Cpw*1000
16550 FNEND
16560 DEF FNRhow(T)
16570 Ro=999.52946+T*(.01269-T*(5.482513E-3-T*1.234147E-5))
16580 RETURN Ro
16590 FNEND
16600 DEF FNPrw(T)
16610 Prw=FNCpw(T)*FNMuw(T)/FNKw(T)
16620 RETURN Prw
16630 FNEND
16640 DEF FNKw(T)
16650 X=(T+273.15)/273.15
16660 Kw=-.92247+X*(2.8395-X*(1.8007-X*(.52577-.07344*X)))
16670 RETURN Kw
16680 FNEND
16690 SUB Plot
16700 COM /Cply/ A(10,10),C(10),B(5),Nop,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
16710 DIM Bs(3)
16720 INTEGER Ii
16730 PRINTER IS 1
16740 Idv=0
16750 BEEP
16760 INPUT "LIKE DEFAULT VALUES FOR PLOT (1=Y,0=N)?",Idv
16770 Opo=0
16780 BEEP
16790 PRINT USING "4X,""Select Option:"""
16800 PRINT USING "6X,""0  q versus delta-T"""
16810 PRINT USING "6X,""1  h versus delta-T"""
16820 PRINT USING "6X,""2  h versus q"""
16830 INPUT Opo
16840 BEEP
16850 INPUT "SELECT UNITS (0=SI,1=ENGLISH)",Iun
16860 PRINTER IS 705
16870 IF Idv<>1 THEN
16880 BEEP
16890 INPUT "ENTER NUMBER OF CYCLES FOR X-AXIS",Cx
16900 BEEP
16910 INPUT "ENTER NUMBER OF CYCLES FOR Y-AXIS",Cy
16920 BEEP
16930 INPUT "ENTER MIN X-VALUE (MULTIPLE OF 10)",Xmin
16940 BEEP
16950 INPUT "ENTER MIN Y-VALUE (MULTIPLE OF 10)",Ymin
16960 ELSE
16970 IF Opo=0 THEN
16980 Cy=3
```

```
16990 Cx=3
17000 Xmin=.1
17010 Ymin=100
17020 END IF
17030 IF Opo=1 THEN
17040 Cy=2
17050 Cx=2
17060 Xmin=.1
17070 Ymin=100
17080 END IF
17090 IF Opo=2 THEN
17100 IF Iun=0 THEN
17110 Cy=3
17120 Cx=2
17130 Xmin=1000
17140 Ymin=100
17150 ELSE
17160 Cy=3
17170 Cx=3
17180 Xmin=100
17190 Ymin=10
17200 END IF
17210 END IF
17220 END IF
17230 BEEP
17240 PRINT "IN;SP1;IP 2300,2200,8300,5800;"
17250 PRINT "SC 0,100,0,100;TL 2,0;"
17260 Sfx=100/Cx
17270 Sfy=100/Cy
17280 BEEP
17290 INPUT "WANT TO BY-PASS CAGE? (1=Y,0=N)",Ibyp
17300 IF Ibyp=1 THEN 18540
17310 PRINT "PU 0,0 PD"
17320 Nn=9
17330 FOR I=1 TO Cx+1
17340 Xat=Xmin*10^(I-1)
17350 IF I=Cx+1 THEN Nn=1
17360 FOR J=1 TO Nn
17370 IF J=1 THEN PRINT "TL 2 0"
17380 IF J=2 THEN PRINT "TL 1 0"
17390 Xa=Xat*J
17400 X=LGT(Xa/Xmin)*Sfx
17410 PRINT "PA";X,",0; XT;"
17420 NEXT J
17430 NEXT I
17440 PRINT "PA 100,0;PU;"
17450 PRINT "PU PA 0,0 PD"
17460 Nn=9
17470 FOR I=1 TO Cy+1
17480 Yat=Ymin*10^(I-1)
17490 IF I=Cy+1 THEN Nn=1
17500 FOR J=1 TO Nn
17510 IF J=1 THEN PRINT "TL 2 0"
17520 IF J=2 THEN PRINT "TL 1 0"
17530 Ya=Yat*J
17540 Y=LGT(Ya/Ymin)*Sfy
17550 PRINT "PA 0,";Y,";YT"
17560 NEXT J
17570 NEXT I
17580 PRINT "PA 0,100 TL 0 2"
```

```
17580 Nn=9
17600 FOR I=1 TO Cx+1
17610 Xat=Xmin*10^(I-1)
17620 IF I=Cx+1 THEN Nn=1
17630 FOR J=1 TO Nn
17640 IF J=1 THEN PRINT "TL 0 2"
17650 IF J>1 THEN PRINT "TL 0 1"
17660 Xa=Xat*J
17670 X=LGT(Xa/Xmin)*Sfx
17680 PRINT "PA";X,",100; XT"
17690 NEXT J
17700 NEXT I
17710 PRINT "PA 100,100 PU PA 100,0 PD"
17720 Nn=9
17730 FOR I=1 TO Cy+1
17740 Yat=Ymin*10^(I-1)
17750 IF I=Cy+1 THEN Nn=1
17760 FOR J=1 TO Nn
17770 IF J=1 THEN PRINT "TL 0 2"
17780 IF J>1 THEN PRINT "TL 0 1"
17790 Ya=Yat*J
17800 Y=LGT(Ya/Ymin)*Sfy
17810 PRINT "PD PA 100,",Y,"YT"
17820 NEXT J
17830 NEXT I
17840 PRINT "PA 100,100 PU"
17850 PRINT "PA 0,-2 SR 1.5,2"
17860 I1=LGT(Xmin)
17870 FOR I=1 TO Cx+1
17880 Xa=Xmin*10^(I-1)
17890 X=LGT(Xa/Xmin)*Sfx
17900 PRINT "PA";X,",0;"
17910 IF I1>=0 THEN PRINT "CP -2,-2:LB10;PR -2,2;LB";I1;""
17920 IF I1<0 THEN PRINT "CP -2,-2:LB10;PR 0,2:LB";I1;""
17930 I1=I1+1
17940 NEXT I
17950 PRINT "PU PA 0,0"
17960 I1=LGT(Ymin)
17970 Y10=10
17980 FOR I=1 TO Cy+1
17990 Ya=Ymin*10^(I-1)
18000 Y=LGT(Ya/Ymin)*Sfy
18010 PRINT "PA 0,";Y,""
18020 PRINT "CP -4,-.25:LB10;PR -2,2:LB";I1;""
18030 I1=I1+1
18040 NEXT I
18050 BEEP
18060 INPUT "WANT USE DEFAULT LABELS (1=Y,0=N)?",Idl
18070 IF Idl<>1 THEN
18080 BEEP
18090 INPUT "ENTER X-LABEL",Xlabel$
18100 BEEP
18110 INPUT "ENTER Y-LABEL",Ylabel$
18120 END IF
18130 IF Opc<2 THEN
18140 PRINT "SR 1,2;PU PA 40,-14;"
18150 PRINT "LB(T:PR -1.5,3 PD PR 1.2,0 PU;PR .5,-4:LBwc;PR .5,1:"
18160 PRINT "LB-T;PR .5,-1:LBsat;PR .5,1:"
18170 IF Iun=0 THEN
18180 PRINT "LB) (F)"
```

```
18190 ELSE
18200 PRINT "LB) (F)"
18210 END IF
18220 END IF
18230 IF Opo=2 THEN
18240 IF Iun=0 THEN
18250 PRINT "SR 1.5,2;PU PA 40,-14;LBq (W/m;SR 1,1.5;PR 0.5,1;LB2;SR 1.5,2:PR
0.5,-1;LB)"
18260 ELSE
18270 PRINT "SR 1.5,2:PU PA 34,-14;LBq (Btu/hr;PR .5,.5;LB.:PR .5,-.5;"
18280 PRINT "LBft;PR .5,1;SR 1,1.5;LB2;SR 1.5,2:PR .5,-1;LB);"
18290 END IF
18300 END IF
18310 IF Opo=0 THEN
18320 IF Iun=0 THEN
18330 PRINT "SR 1.5,2;PU PA -12,40:DI 0,1;LBq (W/m:PR -1,0.5:SR 1,1.5;LB2:SR 1
.5,2;PR 1,.5;LB)"
18340 ELSE
18350 PRINT "SR 1.5,2;PU PA -12,32;DI 0,1;LBq (Btu/hr;PR -.5,.5;LB.:PR .5,.5;"
18360 PRINT "LBft;SR 1,1.5;PR -1,.5;LB2;PR 1,.5;SR 1.5,2:LB)"
18370 END IF
18380 END IF
18390 IF Opo>0 THEN
18400 IF Iun=0 THEN
18410! PRINT "SR 1.5,2;PU PA -12,38:DI 0,1;LBh (W/m;PR -1,.5;SR 1,1.5;LB2;SR 1
.5,2;PR .5,.5;"
18420 PRINT "SR 1.2,2.4;PU PA -12,37:DI 0,1;LBh;PR 1,0.5;LBo;PR -1,0.5;LB (W/m
"
18430 PRINT "PR -1,.5;SR 1,1.5;LB2;SR 1.5,2;PR .5,.5;LB.;PR .5,0;LBK)"
18440 ELSE
18450 PRINT "SR 1.5,2;PU PA -12,28:DI 0,1;LBh (Btu/hr;PR -.5,.5;LB.;PR .5,.5;"
18460 PRINT "LBft;PR -1,.5;SP 1,1.5;LB2;SR 1.5,2;PR .5,.5;LB.;PR .5,.5;LBF)"
18470 END IF
18480 END IF
18490 IF Idl=0 THEN
18500 PRINT "SR 1.5,2;PU PA 50,-15 CP";-LEN(Xlabel$)/2;"0;LB";Xlabel$;""
18510 PRINT "PA -14,50 CP 0,";-LEN(Ylabel$)/2*5/6:"DI 0,1;LB";Ylabel$;""
18520 PRINT "CP 0,0 DI"
18530 END IF
18540 Ipn=0
18550 Xll=1.E+6
18560 Xul=-1.E+6
18570 Icn=0
18580 Ifn=0
18590 Ijoin=1
18600 BEEP
18610 INPUT "WANT TO PLOT DATA FROM A FILE (1=Y,0=N)?",Ol
18620 IF Ol=1 THEN
18630 BEEP
18640 INPUT "ENTER THE NAME OF THE DATA FILE",D_file$
18650 ASSIGN @File TO D_file$
18660 BEEP
18670 BEEP
18680 INPUT "ENTER THE BEGINNING RUN NUMBER",Md
18690 BEEP
18700 INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED",Npairs
18710! BEEP
18720! INPUT "CONNECT DATA WITH LINE (1=Y,0=N)?",Icl
18730 BEEP
18740 PRINTER IS 1
```

```
18750 PRINT USING "4X,""Select a symbol:"""
18760 PRINT USING "5X,""1  Star     2  Plus sign"""
18770 PRINT USING "5X,""3  Circle   4  Square"""
18780 PRINT USING "5X,""5  Rombus"""
18790 PRINT USING "5X,""6  Right-side-up triangle"""
18800 PRINT USING "5X,""7  Up-side-down triangle"""
18810 INPUT Sym
18820 PRINTER IS 705
18830 PRINT "PU DI"
18840 IF Sym=1 THEN PRINT "SM*"
18850 IF Sym=2 THEN PRINT "SM+"
18860 IF Sym=3 THEN PRINT "SMo"
18870 IF Md>1 THEN
18880 FOR I=1 TO (Md-1)
18890 ENTER @File;Ya,Xa
18900 NEXT I
18910 END IF
18920 FOR I=1 TO Npairs
18930 ENTER @File;Ya,Xa
18940 IF I=1 THEN Q1=Ya
18950 IF I=Npairs THEN Q2=Ya
18960 IF Opo=1 THEN Ya=Ya/Xa
18970 IF Opo=2 THEN
18980 Q=Ya
18990 Ya=Ya/Xa
19000 Xa=Q
19010 END IF
19020 IF Xa<Xll THEN Xll=Xa
19030 IF Xa>Xul THEN Xul=Xa
19040 IF Iun=1 THEN
19050 IF Opo<2 THEN Xa=Xa*1.8
19060 IF Opo>0 THEN Ya=Ya*.1751
19070 IF Opo=0 THEN Ya=Ya*.317
19080 IF Opo=2 THEN Xa=Xa*.317
19090 END IF
19100 X=LGT(Xa/Xmin)*Sfx
19110 Y=LGT(Ya/Ymin)*Sfy
19120 Kj=0
19130 CALL Symb(X,Y,Sym,Icl,Kj)
19140 GOTO 19270
19150 IF Sym>3 THEN PRINT "SM"
19160 IF Sym<4 THEN PRINT "SR 1.4,2.4"
19170 IF Icl=0 THEN
19180 PRINT "PA",X,Y,""
19190 ELSE
19200 PRINT "PA",X,Y,"PD"
19210 END IF
19220 IF Sym=3 THEN PRINT "SR 1.2,1.6"
19230 IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,8,4,0:"
19240 IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,6,3,6,3,-6:"
19250 IF Sym=6 THEN PRINT "UC0,5.3,99,3,-8,-6,0,3,8:"
19260 IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,8,6,0,-3,-8:"
19270 NEXT I
19280 PRINT "PU"
19290 BEEP
19300 INPUT "WANT TO LABEL? (1=Y,0=N)",Ilab
19310 IF Ilab=1 THEN
19320 PRINT "SP0;SP2"
19330 BEEP
19340 IF Klab=0 THEN
```

```
19350 Xlab=5
19360 Ylab=95
19370 INPUT "ENTER INITIAL X,Y LOCATIONS",Xlab,Ylab
19380 Xtt=Xlab-5
19390 Ytt=Ylab+9
19400 PRINT "SR 1,1.5"
19410 PRINT "SM;PA",Xtt,Ytt,"LB        %   Heat  File"
19420 Ytt=Ytt-3
19430 PRINT "PA",Xtt,Ytt,"LB       Oil  Flux  Name"
19440 IF Sym=1 THEN PRINT "SM*"
19450 IF Sym=2 THEN PRINT "SM+"
19460 IF Sym=3 THEN PRINT "SMo"
19470 Klab=1
19480 END IF
19490 Kj=1
19500 CALL Symb(Xlab,Ylab,Sym,Icl,Kj)
19510 PRINT "SR 1,1.5;SM"
19520 IF Sym<4 THEN PRINT "PR 2,0"
19530 BEEP
19540 INPUT "ENTER BOP",Bop
19550 IF Bop<10 THEN PRINT "PR 2,0;LB";Bop;""
19560 IF Bop>9 THEN PRINT "PR .5,0;LB";Bop;""
19570 Ihf=0
19580 IF Q1>Q2 THEN Ihf=1
19590 IF Ihf=0 THEN PRINT "PR 4,0;LBInc"
19600 IF Ihf=1 THEN PRINT "PR 4,0;LBDec"
19610 PRINT "PR 2,0;LB";D_file$;""
19620 PRINT "SP0;SP1;SR 1.5,2"
19630 Ylab=Ylab-5
19640 END IF
19650 BEEP
19660 ASSIGN @File TO *
19670 Xll=Xll/1.2
19680 Xul=Xul*1.2
19690! GOTO 9040
19700 END IF
19710 PRINT "PU SM"
19720 BEEP
19730 INPUT "WANT TO PLOT A POLYNOMIAL (1=Y,0=N)?",Go_on
19740 IF Go_on=1 THEN
19750 BEEP
19760 PRINTER IS 1
19770 PRINT USING "4X,""Select line type:"""
19780 PRINT USING "5X,""0      Solid line"""
19790 PRINT USING "5X,""1      Dashed"""
19800 PRINT USING "5X,""2...5 Longer line - dash"""
19810 INPUT Ipn
19820 PRINTER IS 705
19830 BEEP
19840 INPUT "SELECT (0=LIN,1=LOG(X,Y))",Ilog
19850 Iprnt=1
19860 CALL Poly
19870 IF Ifn=0 THEN
19880 BEEP
19890 INPUT "ENTER NUMBER OF FILES TO JOIN?",Njoin
19900 END IF
19910 Ijoin=0
19920 IF Ifn=Njoin THEN Ijoin=1
19930 IF Ifn=0 OR Ijoin=1 THEN
19940 FOR Ij=0 TO 2
```

```
19950 9s(Ij)=9s(Ij)+9(Ij)
19960 NEXT Ij
19970 Ifn=Ifn+1
19980 END IF
19990 IF Njoin=Ifn THEN
20000 FOR Ij=0 TO 3
20010 9(Ij)=9s(Ij)/Njoin
20020 9s(Ij)=0
20030 NEXT Ij
20040 Ifn=0
20050 ELSE
20060 GOTO 19600
20070 END IF
20080 BEEP
20090 INPUT "ENTER Y LOWER AND UPPER LIMITS",Yll,Yul
20100 FOR Xx=0 TO Cx STEP Cx/200
20110 Xa=Xmin*10^Xx
20120 IF Xa<Xll OR Xa>Xul THEN 20390
20130 Icn=Icn+1
20140 Pu=0
20150 IF Ipn=1 THEN Idf=Icn MOD 2
20160 IF Ipn=2 THEN Idf=Icn MOD 4
20170 IF Ipn=3 THEN Idf=Icn MOD 9
20180 IF Ipn=4 THEN Idf=Icn MOD 16
20190 IF Ipn=5 THEN Idf=Icn MOD 28
20200 IF Idf=1 THEN Pu=1
20210 IF Opo=0 THEN Ya=FNPoly(Xa)
20220 IF Opo=2 AND Ilog=0 THEN Ya=Xa/FNPoly(Xa)
20230 IF Opo=2 AND Ilog=1 THEN Ya=FNPoly(Xa)
20240 IF Opo=1 THEN Ya=FNPoly(Xa)
20250 IF Ya<Ymin THEN 20390
20260 IF Ya<Yll OR Ya>Yul THEN 20390
20270 IF Iun=1 THEN
20280 IF Opo<2 THEN Xa=Xa*1.9
20290 IF Opo>0 THEN Ya=Ya*.1761
20300 IF Opo=0 THEN Ya=Ya*.317
20310 IF Opo=2 THEN Xa=Xa*.317
20320 END IF
20330 Y=LGT(Ya/Ymin)*Sfy
20340 X=LGT(Xa/Xmin)*Sfx
20350 IF Y<0 THEN Y=0
20360 IF Y>100 THEN GOTO 20390
20370 IF Pu=0 THEN PRINT "PA",X,Y,"PD"
20380 IF Pu=1 THEN PRINT "PA",X,Y,"PU"
20390 NEXT Xx
20400 PRINT "PU"
20410 GOTO 19600
20420 END IF
20430 BEEP
20440 INPUT "WANT TO PLOT REILLY'S DATA? (1=Y,0=N)",Irly
20450 IF Opo=0 OR Opo=1 THEN
20460 Xll=3
20470 Xul=20
20480 END IF
20490 IF Opo=2 THEN
20500 Xll=10000
20510 Xul=100000
20520 END IF
20530 IF Irly=1 THEN
20540 Yll=20
```

```
20550 Yul=70
20560 BEEP
20570 INPUT "ENTER LOWER AND UPPER Y-LIMITS FOR PLOTTING",Y11,Yul
20580 FOR Xx=0 TO Cx STEP Cx/200
20590 Xa=Xmin*10^Xx
20600 IF Xa<X11 OR Xa>Xul THEN 20730
20610 X1=LOG(Xa)
20620 IF Opo=0 THEN Y1=-2.5402837E-1+X1*(4.9720151-X1*2.5134787E-1)
20630 IF Opo=1 THEN Y1=-2.5402837E-1+X1*(3.9720151-X1*2.5134787E-1)
20640 IF Opo=2 THEN Y1=-3.7073801E-1+X1*(8.7259190E-1-X1*6.9925942E-3)
20650 Ya=EXP(Y1)
20660 Y=LGT(Ya/Ymin)*Sfy
20670 X=LGT(Xa/Xmin)*Sfx
20680 Ipu=0
20690 IF Y<Y11 THEN Ipu=1
20700 IF Y>Yul THEN GOTO 20730
20710 IF Ipu=0 THEN PRINT "PA",X,Y,"PD"
20720 IF Ipu=1 THEN PRINT "PA",X,Y,"PU"
20730 NEXT Xx
20740 PRINT "PU"
20750 END IF
20760 BEEP
20770 INPUT "WANT TO PLOT ROHSENOW CORRELATION? (1=Y,0=N)",Irohs
20780 IF Irohs=1 THEN
20790 Y11=15
20800 Yul=90
20810 BEEP
20820 INPUT "ENTER Tsat (Deg C)",Tsat
20830 Csf=.0040
20840 BEEP
20850 INPUT "ENTER Csf (DEF=0.004)",Csf
20860 Tf=Tsat+2
20870 FOR Xx=0 TO Cx STEP Cx/200
20880 Xa=Xmin*10^Xx
20890 IF Xa<X11 OR Xa>Xul THEN 21170
20900 X1=LOG(Xa)
20910 IF Opo<2 THEN Tf=Tsat+Xa/2
20920 Rho=FNRho(Tf)
20930 K=FNK(Tf)
20940 Mu=FNMu(Tf)
20950 Cp=FNCp(Tf)
20960 Hfg=FNHfg(Tsat)
20970 Ni=Mu/Rho
20980 Pr=Cp*Mu/K
20990 Omega=Csf*Hfg/Cp*((.014/(9.81*Rho))^.5/(Mu*Hfg))^(1./3)*Pr^1.7
21000 IF Opo=0 THEN Ya=(Xa/Omega)^3
21010 IF Opo=1 THEN Ya=(Xa/Omega)^3/Xa
21020 IF Opo=2 THEN Ya=Xa^(2./3)/Omega
21030 IF Opo=2 THEN
21040 Tfc=Tsat+Xa/Ya*.5
21050 IF ABS(Tf-Tfc)>.01 THEN
21060 Tf=(Tf+Tfc)*.5
21070 GOTO 20920
21080 END IF
21090 END IF
21100 Y=LGT(Ya/Ymin)*Sfy
21110 X=LGT(Xa/Xmin)*Sfx
21120 Ipu=0
21130 IF Y<Y11 THEN Ipu=1
21140 IF Y>Yul THEN 21170
```

```
21150 IF Ipu=0 THEN PRINT "PA",X,Y,"PD"
21160 IF Ipu=1 THEN PRINT "PA",X,Y,"PU"
21170 NEXT Xx
21180 PRINT "PU"
21190 END IF
21200 BEEP
21210 INPUT "WANT TO QUIT (1=Y,0=N)",Iqt
21220 IF Iqt=1 THEN 21240
21230 GOTO 19550
21240 PRINT "PU PA 0,0 SP0"
21250 SUBEND
21260 SUB Symb(X,Y,Sym,Icl,Kj)
21270 IF Sym>3 THEN PRINT "SM"
21280 IF Sym<4 THEN PRINT "SR 1.4,2.4"
21290 Yad=0
21300 IF Kj=1 THEN Yad=.9
21310 IF Icl=0 THEN
21320 PRINT "PA",X,Y+Yad,""
21330 ELSE
21340 PRINT "PA",X,Y+Yad,"PD"
21350 END IF
21360 IF Sym>3 THEN PRINT "SR 1.2,1.6"
21370 IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,8,4,0;"
21380 IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,6,3,6,3,-6;"
21390 IF Sym=6 THEN PRINT "UC0,5.3,99,3,-9,-6,0,3,9;"
21400 IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,9,6,0,-3,-9;"
21410 IF Kj=1 THEN PRINT "SM;PR 0,-.9"
21420 SUBEND
21430 SUB Purg
21440 BEEP
21450 INPUT "ENTER FILE NAME TO BE DELETED",File$
21460 PURGE File$
21470 GOTO 21440
21480 SUBEND
21490 SUB Tdcn
21500 COM /Cc/ C(7),Ical
21510 DIM Emf(1)
21520 DATA 0.10086091,25727.94369,-767345.8295,78025595.81
21530 DATA -9247486589,6.97688E+11,-2.66192E+13,3.94078E+14
21540 READ C(*)
21550 BEEP
21560 INPUT "GIVE A NAME FOR FILE TO BE CREATED",File$
21570 BEEP
21580 INPUT "SELECT TUBE (0=WH,1=HF,2=WT)",Itt
21590 BEEP
21600 INPUT "SELECT THERMOCOUPLE TYPE (0=NEW,1=OLD)",Ical
21610 IF Itt=2 THEN Di=.0127
21620 CREATE BDAT File$,1
21630 ASSIGN @File TO File$
21640 OUTPUT @File;Itt
21650 J=0
21660 BEEP
21670!INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Date$
21680!OUTPUT 709;"TD";Date$
21690!OUTPUT 709;"TD"
21700!ENTER 709;Date$
21710 PRINTER IS 1
21720 PRINT
21730 PRINT "             Month, date and time: ";Date$
21740 PRINT
```

```
21750 PRINT USING "10X,"" Fms       Tin       Tev       Vw^2      Tdrop"""
21760 IF K=0 THEN
21770 PRINTER IS 701
21780 PRINT
21790 PRINT "             Month, date and time: ";Date$
21800 IF Itt=0 THEN PRINT USING "10X,""Tube Type:              Wieland Smooth"""
21810 IF Itt=1 THEN PRINT USING "10X,""Tube Type:              High Flux"""
21820 IF Itt=2 THEN PRINT USING "10X,""Tube Type:              Turbo-B"""
21830 PRINT
21840 PRINT USING "10X,"" Fms       Tin       Tev       Vw^2       Tdrop"""
21850 PRINTER IS 1
21860 K=1
21870 END IF
21880 BEEP
21890 INPUT "ENTER FLOWMETER READING",Fms
21900 OUTPUT 709;"AR AF0 AL4 VR1"
21910 FOR L=0 TO 4
21920 OUTPUT 709;"AS SA"
21930 IF L>0 AND L<4 THEN 22010
21940 S=0
21950 FOR I=0 TO 9
21960 ENTER 709;E
21970 S=S+E
21980 NEXT I
21990 IF L=0 THEN Emf(0)=ABS(S/10)
22000 IF L=4 THEN Emf(1)=ABS(S/10)
22010 NEXT L
22020 OUTPUT 709;"AR AF00 AL00 VR1"
22030 OUTPUT 709;"AS SA"
22040 Etp=0
22050 FOR I=0 TO 9
22060 ENTER 709;Et
22070 Etp=Etp+Et
22080 NEXT I
22090 Etp=Etp/10
22100 Tin=FNTvsv(Emf(1))
22110 Tev=FNTvsv(Emf(0))
22120 Grad=37.9953+.104399*Tin
22130 Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(8.92006E-6-Fms*(1.23688E-7-Fms*4.31987
E-10)))
22140 Vw=Mdot/(1000*PI*Di^2)*4
22150 Tdrop=Etp*1.E+6/(10*Grad)
22160 PRINT USING "10X,3(DD.DD,4X),1X,Z.DD,4X,MZ.4D";Fms,Tin,Tev,Vw^2,Tdrop
22170 BEEP
22180 INPUT "WANT TO ACCEPT THIS DATA SET? (1=Y,0=N)",Ok
22190 J=J+1
22200 IF Ok=0 THEN
22210 J=J-1
22220 GOTO 21880
22230 ELSE
22240 OUTPUT @File;Fms,Emf(*),Etp
22250 PRINTER IS 701
22260 PRINT USING "10X,3(DD.DD,4X),1X,Z.DD,4X,MZ.4D";Fms,Tin,Tev,Vw^2,Tdrop
22270 PRINTER IS 1
22280 BEEP
22290 INPUT "WILL THERE BE ANOTHER DATA SET? (1=Y,0=N)",Go_on
22300 IF Go_on=1 THEN 21880
22310 END IF
22320 ASSIGN @File TO *
22330 PRINTER IS 701
```

```
22340 PRINT
22350 PRINT USING "10X,""NOTE: "",ZZ,"" data sets are stored in file "",15A";J,F
ile$
22360 PRINTER IS 1
22370 SUBEND
22380 SUB Uoprt
22390 PRINTER IS 1
22400 BEEP
22410 INPUT "Enter Uo File Name",File$
22420 BEEP
22430 INPUT "Number of Data Runs",Nrun
22440 INPUT "Do You Want a Plot File?(1=Y,0=N)",Iplot
22450 BEEP
22460 IF Iplot=1 THEN
22470 INPUT "Give Plot File Name",P_file$
22480 CREATE BDAT P_file$,4
22490 ASSIGN @Plot TO P_file$
22500 END IF
22510 PRINTER IS 701
22520 PRINT
22530 PRINT
22540 PRINT USING "10X,""   Water Vel         Uo"""
22550 ASSIGN @File TO File$
22560 IF Iplot=1 THEN ASSIGN @File1 TO P_file$
22570 FOR I=1 TO Nrun
22580 ENTER @File;Vw,Uo
22590 IF Iplot=1 THEN OUTPUT @File1;Vw,Uo
22600 PRINT USING "15X,D.DD,5X,MZ.3DE";Vw,Uo
22610 NEXT I
22620 ASSIGN @File TO *
22630 ASSIGN @File1 TO *
22640 PRINT USING "10X,""NOTE: "",ZZ,"" data sets are stored in file "",15A";Nru
n,File$
22650 IF Iplot=1 THEN
22660 PRINT USING "10X,""NOTE: "",ZZ,"" X-Y Pairs are stored in file "",15A";Nru
n,P_file$
22670 END IF
22680 PRINTER IS 1
22690 SUBEND
22700 SUB Select
22710 COM /Idp/ Idp
22720 BEEP
22730 PRINTER IS 1
22740 PRINT USING "4X,""Select option:"""
22750 PRINT USING "6X,"" 0 Taking data or re-processing previous data"""
22760 PRINT USING "6X,"" 1 Plotting data on Log-Log """
22770 PRINT USING "6X,"" 2 Plotting data on Linear"""
22780 PRINT USING "6X,"" 3 Make cross-plot coefft file"""
22790 PRINT USING "6X,"" 4 Re-circulate water"""
22800 PRINT USING "6X,"" 5 Purge"""
22810 PRINT USING "6X,"" 6 T-Drop correction"""
22820 PRINT USING "6X,"" 7 Print Uo File"""
22830 PRINT USING "6X,"" 8 Modify X-Y file"""
22840 PRINT USING "6X,"" 9 Move"""
22850 PRINT USING "6X,""10 Comb/Fixup"""
22860 INPUT Idp
22870 IF Idp=0 THEN CALL Main
22880 IF Idp=1 THEN CALL Plot
22890 IF Idp=2 THEN CALL Plin
22900 IF Idp=3 THEN CALL Coef
```

```
22910 IF Idp=4 THEN CALL Main
22920 IF Idp=5 THEN CALL Purg
22930 IF Idp=6 THEN CALL Tdcn
22940 IF Idp=7 THEN CALL Ucprt
22950 IF Idp=8 THEN CALL Xymod
22960 IF Idp=9 THEN CALL Move
22970 IF Idp=10 THEN CALL Comb
22980 SUBEND
22990 SUB Xymod
23000 PRINTER IS 1
23010 BEEP
23020 INPUT "ENTER FILE NAME",File$
23030 ASSIGN @File1 TO File$
23040 BEEP
23050 INPUT "ENTER NUMBER OF X-Y PAIRS",Np
23060 BEEP
23070 INPUT "ENTER NEW FILE NAME",File2$
23080 CREATE BDAT File2$,5
23090 ASSIGN @File2 TO File2$
23100 BEEP
23110 INPUT "ENTER NUMBER OF X-Y PAIRS TO BE DELETED",Ndel
23120 IF Ndel=0 THEN 23150
23130 FOR I=1 TO Ndel
23140 BEEP
23150 INPUT "ENTER DATA SET NUMBER TO BE DELETED",Nd(I)
23160 NEXT I
23170 FOR J=1 TO Np
23180 ENTER @File1;X,Y
23190 FOR I=1 TO Ndel
23200 IF Nd(I)=J THEN 23240
23210 NEXT I
23220 OUTPUT @File2;X,Y
23230 PRINT J,X,Y
23240 NEXT J
23250 PRINTER IS 701
23260 ASSIGN @File1 TO *
23270 ASSIGN @File2 TO *
23280 SUBEND
23290 SUB Move
23300! FILE NAME: MOVE
23310!
23320 DIM Bop(66),A(66),B(66),C(66),D(66),E(66),F(66),G(66),H(66),J(66),K(66),L(
66),M(66)
23330 DIM Told$(66)[14],N(66),Vr(66),Ir(66)
23340 BEEP
23350 INPUT "OLD FILE TO MOVE",D2_file$
23360 ASSIGN @File2 TO D2_file$
23370 ENTER @File2;Nrun,Date$,Ldtc1,Ldtc2,Itt
23380 FOR I=1 TO Nrun
23390 ENTER @File2;Bop(I),Told$(I)
23400 ENTER @File2;A(I),B(I),C(I),D(I),E(I),F(I),G(I),H(I),J(I),K(I),L(I),M(I),N
(I)
23410 ENTER @File2;Vr(I),Ir(I)
23420 NEXT I
23430 ASSIGN @File2 TO *
23440 BEEP
23450 INPUT "SHIFT DISK AND HIT CONTINUE",Ok
23460 BEEP
23470 INPUT "INPUT BDAT SIZE",Size
23480 CREATE BDAT D2_file$,Size
```

```
23490 ASSIGN @File1 TO O2_file$
23500 OUTPUT @File1;Nrun,Date$,Ldtc1,Ldtc2,Itt
23510 FOR I=1 TO Nrun
23520 OUTPUT @File1;Bop(I),Told$(I)
23530 OUTPUT @File1;A(I),B(I),C(I),D(I),E(I),F(I),G(I),H(I),J(I),K(I),L(I),M(I),
N(I)
23540 OUTPUT @File1;Vr(I),Ir(I)
23550 NEXT I
23560 ASSIGN @File1 TO *
23570! RENAME "TEST" TO O2_file$
23590 BEEP 2000,.2
23590 BEEP 4000,.2
23600 BEEP 4000,.2
23510 PRINT "DATA FILE MOVED"
23520 SUBEND
23630 SUB Comb
23640! FILE NAME: COMB
23650!
23660 DIM Emf(12)
23670 BEEP
23680 INPUT "OLD FILE TO FIXUP",O2_file$
23690 ASSIGN @File2 TO O2_file$
23700 O1_file$="TEST"
23710 CREATE BDAT O1_file$,20
23720 ASSIGN @File1 TO O1_file$
23730 ENTER @File2;Nrun,Date$,Ldtc1,Ldtc2,Itt
23740 Nrunm=20
23750 IF K=0 THEN OUTPUT @File1;Nrunm,Date$,Ldtc1,Ldtc2,Itt
23760 FOR I=1 TO Nrun
23770 ENTER @File2;Bop,Told$,Emf(*),Vr,Ir
23780 OUTPUT @File1;Bop,Told$,Emf(*),Vr,Ir
23790 NEXT I
23800 ASSIGN @File2 TO *
23810! RENAME "TEST" TO O2_file$
23820 BEEP 2000,.2
23830 BEEP 4000,.2
23840 BEEP 4000,.2
23850 BEEP
23860 INPUT "WANT TO ADD ANOTHER FILE (1=Y,0=N)?",Oka
23870 IF Oka=1 THEN
23880 K=1
23890 BEEP
23900 INPUT "GIVE NEW FILE NAME",Nfile$
23910 ASSIGN @File2 TO Nfile$
23920 GOTO 23730
23930 END IF
23940 ASSIGN @File2 TO *
23950 SUBEND
```

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